UNIVERSITY OF CAPE COAST

IMPROVING THE TEACHING AND LEARNING OF ORGANIC CHEMISTRY IN SENIOR HIGH SCHOOLS

NATHAN OHENE GYANG

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BY

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Thesis submitted to the Department of Science Education of the Faculty of Science and Technology Education, College of Education Studies, University of Cape Coast, in partial fulfilments for the award of Doctor of Philosophy degree in Science Education

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: ………………………... Date: ……………………….

Name: Nathan Ohene Gyang

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature: …………………… Date: ……………

Name: Prof. Victor Y. A. Barku

Co-supervisor's Signature: …………………………... Date: ……………

Name: Dr. Kenneth Adu-Gyamfi

ABSTRACT

The study focused on improving teaching and learning organic chemistry in senior high schools (SHS), through design-based research (DBR) using both qualitative and quantitative methods. This DBR approach comprised preliminary research, design and development, implementation and assessment, and reflection and documentation phases. In the preliminary research phase, an organic chemistry diagnostic test was developed to explore students' conceptual understanding of organic chemistry. Nine chemistry teachers and 276 SHS 3 students were sampled through purposive and simple random sampling procedures respectively to participate in the preliminary phase. Subsequently, 14 students and the 9 teachers were interviewed regarding barriers and opportunities in teaching and learning organic chemistry. At the design and development phase, theory-based organic chemistry instructional plan (TB-OCIP) was developed and validated by two experts and through iterative cycles. TB-OCIP was implemented in an intact SHS 2 class of 22 students. Data were collected using questionnaire, pre- and post-tests, group interviews, and exit cards in this phase of this DBR. The quantitative data were analysed with percentages, means, standard deviation, and Wilcoxon signed ranked test. The qualitative data were thematically analysed. TB-OCIP significantly improved students' conceptual understanding of organic chemistry. Therefore, Ghana Education Service through SHS administrators, should organise professional development programmes for teachers to effectively use TB-OCIP in teaching chemistry concepts.

KEY WORDS

Design-based research

Organic chemistry

Students

Teachers

Theory-Based Organic Chemistry Instructional Plan (TB-OCIP)

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DEDICATION

To my wife and children

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CHAPTER ONE

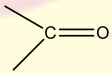
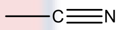
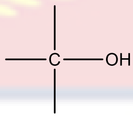
INTRODUCTION

Background of the Study

Effective instruction is directly tied to instructional approach used in classrooms (Majahan & Singh, 2003; Rasmitadila, Widyasari, Prasetyo, Rachmadtullah, Samsudin & Aliyyah, 2021). The selection of instructional approaches is, to a greater extent, dependent on both teachers' skills and learners' capabilities to achieve the goals of the lesson. It is, therefore, expected of teachers to identify a practical instructional approach to teaching concepts. Agboola and Oloyede (2007) reported that teachers should look for ways of developing and employing various techniques in teaching. Because learning is a dynamic process that requires internal modification on the part of the learner to acquire the required abilities. Hence, to enhance the effectiveness of instruction, strategies employed should take into account the dynamic nature of learning (Abdurrahaman, 2010). Instructional strategies can be fundamentally categorised into two broad areas; learner-centred and teacher-centred (Tara, 2005). In a classroom that is based around the instructor, the teacher assumes the primary role of imparting knowledge to the students. According to Antwi, Anderson, and Sakyi-Hagan (2015), teacher-centred lessons are direct instructions typically entailing the presentation of teaching and learning materials, guided practice, correction, and feedback, and talking aloud by the teacher. Furthermore, it is believed that the teacher is the prime mover of educational experiences (Peng, 2023). A teacher-centred approach is a method whereby the teacher instructs students who are unfamiliar with, lack prior knowledge of, or have no experience with a certain concept (Gengle, Abel & Mohammed, 2017). Many chemical educators choose the direct instructional approach in lesson delivery as it provides maximum content coverage and is very convenient for them (Tenaw, 2015). However, the direct teaching approach has long been criticised for causing dislike for science-related subjects and courses and a lack of understanding of a basic concept. The cause is principally due to dull presentations, too much writing, and minimal practical activities where students act as recipients of information (Shamsudin, Abdullah & Yaamat, 2013).

In contrast to the teacher-centred instructional strategy, the student-centred approach places the student at the centre of the learning process. According to Abdurrahman (2010), learners engage in active participation in the decision-making process on their learning objectives and the sort of support required. A student-centred approach considers how teachers might prime students' prior knowledge, disclose knowledge organizations, boost motivation, and enhance skill acquisition. Gengle et al. (2017) explained that the student-centred approach provides students with holistic development, reflection, and self-awareness, leading to their active participation in the classroom. The effect is because student-centred approaches take into consideration the needs, skills, and interests of the learner. The constructivist learning model fundamentally influences the students-centred approach. Vale, Weaven, Davies, and Hooley (2015) assert that a significant portion of the existing literature on this subject demonstrates a preference for this method, as seen by the prevalent use of alternative terms such as personalised learning, independent learning, autonomous learning, and genuine learning. In a similar vein, student-centred learning affords learners with increased autonomy and authority in determining their selection of subject matter, approach to learning, and pace of study (Sparrow, Sparrow & Swan, 2000). In Ghana, chemistry is one of the major subjects for senior high school (SHS) science students because of its presumed relevance to students' career goals and everyday lives. As part of the general aims of teaching chemistry at the SHS level, the 2010 chemistry curriculum outlines the objectives for chemistry instruction. These include raising awareness of the connections between chemistry and other fields of study or professions, the significant effects that chemical processes and their applications have on society and the environment, and the development of the capacity to connect the chemistry taught in the classroom to the chemistry used in contemporary and traditional industries or in real-world settings; making the topic engaging and inspiring by creating hands-on activities for students to deepen their comprehension of the topic; teaching students how to design experiments using their theoretical concepts in order to tackle real-world chemical problems; supporting an exploratory approach to chemistry education and making chemistry classes problem-solving-based (MOE, 2010, p. ii).

An in-depth analysis of the SHS 2010 chemistry curriculum reveals that there are 13 sections, five for SHS 1, six for SHS 2, and two for SHS 3, with broad topics covering both inorganic and organic chemistry (MOE, 2010). Organic chemistry is a broad field of study with extensive, complex information that frequently overwhelms students' learning processes (Knudston, 2015). Hence, all organic chemistry concepts to be learned at the SHS level are grouped under two broad categories: hydrocarbons and derived hydrocarbons. Students are expected to be introduced to the study of the chemistry of carbon compounds (organic chemistry) at SHS 2 in Section 6. According to MOE (2010), the chemistry of carbon compounds requires that students master key concepts in their interactions with organic chemistry and also, demonstrate general awareness of sources, preparation, structural formula, nomenclature, the physical and chemical properties of hydrocarbons and derived hydrocarbons, and apply these chemical principles to explain the observed properties.

Hydrocarbons come in a variety of forms, including aromatic hydrocarbons (arenes), alkanes, cycloalkanes, alkenes, and alkynes. The majority of hydrocarbons on Earth are naturally found in petroleum, which is a source of abundant carbon and hydrogen from decayed organic materials that may combine to form apparently endless chains of carbon (McMurry, 2000). Also, hydrocarbons can be divided into three groups: saturated, unsaturated, and aromatic hydrocarbons. Saturated hydrocarbons are the simplest of them, called alkanes. The main components of petroleum fuels are saturated hydrocarbons, which can be found as either branched or linear compounds (Silberberg, 2004). Unsaturated hydrocarbons have one or more double bonds (alkenes) or triple bonds (alkynes) between the carbon atoms (Silberberg, 2004). Aromatic hydrocarbons are flat, cyclic, and conjugated. Many aromatic hydrocarbons have distinct smells that distinguish them. Benzene (C_6H_6) is the commonest base for most aromatic compounds (Vollhardt & Schore, 1997). For the other group of organic compounds, derived hydrocarbons (functional groups) have specific substituents within their molecules that are considered sites of chemical reactivity and responsible for the chemical characteristics of these organic molecules (Fessenden & Fessenden, 1990). The existence of this site makes it possible to predict chemical reactions, understand how chemical substances behave, and plan chemical synthesis in a methodical manner. Other than carbon or hydrogen, a derived hydrocarbon includes nitrogen, oxygen, sulphur, phosphorus, and halogens as well as heteroatoms or pi bonds. Derived hydrocarbons can be categorised into three: RX group (X is an electronegative element), compounds containing the  group, and  group. According to MOE (2010), students are to be exposed to some of the most common functional groups; alcohol (), carboxylic acids ($-CO_2H$), esters ($-CO_2R$), and amines ($-NH_2$). Several researchers have categorically reported varying degrees of challenges of studying chemistry over the years due to its complexity and abstract nature (Childs & Sheehan, 2009; Jimoh, 2005; Woldeamanuel, Atagana, & Engida, 2014). Most learners generally perceive organic chemistry as a problematic area of learning in chemistry (Johnstone, 2006; 2010; O'Dwyer & Childs, 2017), and learners do face difficulties in almost all concepts in organic chemistry at the introductory level (Childs & Sheehan, 2009; Jimoh, 2005; Johnstone, 2006; Kurbanoglu, Taskesenligil, & Sozbilir, 2006; O'Dwyer & Childs, 2017). A study conducted by Agogo, and Onda (2014) in SHS in Benue State, Nigeria, reported that conceptual understanding of hydrocarbons and derived hydrocarbons was difficult to students. Similar findings have been reported by Uchegbu, Oguoma, Elenwoke, and Ogbuogu (2016). In Ghana, studies conducted by Adu-Gyamfi, Ampiah, and Appiah (2012; 2013) amongst SHS students in the Kumasi metropolis opined that students have difficulty with the IUPAC nomenclature of organic compounds, as well as lack the ability to identify derived hydrocarbons and the exact number of carbon atoms present in the parent chain. Further, an investigation conducted by Donkoh (2017) amongst SHS science students in Ghana reported that students perceived organic chemistry topics such as hydrocarbons and derived hydrocarbons to be very difficult to understand.

Although students perceived the study of organic chemistry as difficult (Sibomana, Karegeya & Sentongo, 2021), its importance has been acknowledged universally and is considered an essential requirement for students who are desirous of pursuing science-related careers (Twoli, 2006). The development of science, including organic chemistry, has resulted in the dependency of society on the product of the organic chemical industry to preserve the current standard of livelihood and improve the quality of everyday life (Clayden, Greeves, Warren & Wothers, 2005). This assertion is also supported by Ghosh (2015), that chemical industries affect our daily lives in several ways, as organic chemistry is associated with food, clothing, furniture, and medicines. The emergence of organic chemistry has been able to improve life expectancy as we can live longer, healthier, and more comfortably through the manufacturing of lifesaving drugs, vitamins, sugar, starch, milk, and proteins (Ghosh, 2015; Jain & Joshi, 2012). Furthermore, the manufacturing of most life-essential products is all based on the application of organic chemistry (Joules & Mills, 2000).

Also, crude oil, which represents one of the significant sources of organic compounds, has generated a wide range of products, such as hydrocarbons and derived hydrocarbons, whose application in our present lifestyle depends on them (Bansal, 2001). Although organic chemistry is essential and occupies a central position in life on the planet (Solomons, Fryhle & Snyder 2014), it has been plagued with difficulties in conceptual understanding, as mentioned earlier, resulting in poor performance and a negative attitude about the subject.

Some chemical educators and researchers have claimed that numerous abstract concepts that are challenging for most students to understand are included in chemistry topics (Coll & Treagust, 2001; Sirhan, 2007; Taber, 2002). Based on this, most students believe science is a difficult area of study and consider organic chemistry one of the most challenging subjects (Johnstone, 2010). This negative perception held by students concerning their conceptual understanding of organic chemistry could culminate in poor mastery of skills and, subsequently, poor performance in the subject.

Students' conceptual understanding of chemistry is influenced by external and internal factors that have a direct effect on their learning outcomes (Susilaningsih, Fatimah & Nuswowati, 2019). Attitudes of teachers towards students' abilities in chemistry (Abudu & Gbadamosi, 2014; Ogembo, 2012); insufficient teaching and learning resources (Twoli, 2006); students' attitudes towards chemistry (Dhindsa & Chung, 2003; Kyalo, 2016; Olatoye, 2002; Salta & Tzougraki, 2004); students' anxiety towards organic chemistry (Kurbanoglu & Akim, 2013); teachers' academic and professional qualifications (Ibezim, 2018; Ouma, 2011; Yala & Wanjohi, 2011); teachers' misconceptions and factual difficulties in organic chemistry (Adu-Gyamfi & Asaki, 2021 Annim-Eduful & Adu-Gyamfi, 2021) are all commonly cited as causes of low chemistry achievement. However, the majority of students facing difficulty at more profound conceptual levels of knowledge in organic chemistry attributed their challenges to the teaching-learning process (Gafoor & Shilna, 2012; Hassan, 2015; Kyalo, 2016; Ouma, 2011; Salame, Patel & Suleman, 2019; Sirhan, 2007). A similar report linked poor performance and a lack of conceptual understanding in science-related subjects such as organic chemistry to the instructional approach used in the organic chemistry classroom (Wanbugu, Chanegeiywo & Ndritu, 2013). Eticha and Ochonogor (2015), in their investigation, attributed students' difficulties in conceptual understanding of organic chemistry to inappropriate teaching approaches used by teachers. The phenomenon is possibly due to the abstract nature in which the subject is introduced and taught.

Chang (2005) opined that chemistry is replete with various chemical terminologies and languages, as well as several notions that are not concrete. Moreover, the topic exhibits characteristics that are uncommon in other scientific disciplines due to its three levels of study: macroscopic (perceptible properties), microscopic (particles composed of the substance), and symbolic (substance identity symbols) (Rusminiati, Karyasa & Suardana, 2015). Understanding chemistry is a complex human activity in which learners must learn, relate to, and differentiate amongst these three levels of presentation to attain conceptual understanding and effective learning in chemistry (Dori & Hameiri, 2003). However, it appears that chemistry teachers highlight the symbolic level in their instruction and inadequately emphasise the microscopic and macroscopic levels. The intensive use of the teaching strategy in chemistry, which is mostly at the symbolic level, is the main obstacle to comprehension in chemistry (Gabel, 1999). Therefore, it is suggested that the instructional approach used in delivering organic chemistry lessons be altered to suit the characteristics of the student to remedy the observed challenges (Salame et al., 2019).

It must be noted that several approaches influence the way students learn (Bennett, 2003). For this and many other reasons, MOE (2010) recommended that all chemistry teachers employ instructional strategies that maximise student participation in the classroom and discourage the use of rote learning and drill-oriented methods. Ajaja (2013) postulated four views that mainly affect the instruction of science-related subjects and courses; the transmission of knowledge, discovery learning, a developmental view of learning, and constructivism. According to constructivism, which emphasizes the active production and transformation of information, students learn well when they actively construct their knowledge and understanding (Santrock, 2001). Therefore, to facilitate conceptual understanding of a fundamental concept in organic chemistry, conscious efforts must be made to shift from a teacher-centred learning approach to a student-centred approach supported by a technology-based learning environment with the capacity to encourage students to engage actively in the learning process. Fundamentally, a well-designed, organised learning environment may improve learning quality and motivate students to show their conceptual grasp of learning materials (Mason, 2007). Such settings improve students' academic performance in organic chemistry through the application of different interactive instructional strategies (Miles, 2015).

There is a plethora of student-centred instructional approaches employed successfully by chemical educators and researchers to improve performance, culminating in enhanced interest in the subject (Ajayi, 2017; Gyasi, Ofoe & Samlafo, 2018; Hanson, 2017; Rice, 2016; Sarkodie & Adu-Gyamfi, 2015; Sloop et. al, 2016). Sloop (2016) employed a problem-solving scaffold with undergraduate students in the USA and found that after putting the intervention into practice, students' proficiency in organic chemistry improved. An investigation conducted by Ajayi (2017) with senior secondary students revealed in Nigeria that students demonstrated improvement in their interest in the learning of organic chemistry after experiencing hands-on activity-based instruction. Gyasi et al. (2018) said in a study conducted in Effiduase, Ghana, amongst SHS students that academic performance in organic chemistry improved when molecular model sets were used to teach the nomenclature of organic compounds. Sarkodie and Adu-Gyamfi (2015) asserted that both students' attitudes and performance improved following seven weeks of instruction on IUPAC writing and naming structural formulas of hydrocarbons with the ball-and-stick models.

Also, Hanson (2017), in a study to improving the academic performance of secondary school students in organic chemistry in Ghana through context-based learning and micro activities found that after eight weeks of intervention, students' thinking habits improved as they could use the principles, they had learned to tackle issues in a different setting. Rice (2016) designed and implemented an organic chemistry visualisation programme to promote Ireland's second-cycle chemistry students' understanding how various representations of organic molecules interact with one another and how to anticipate the reactivity and physical characteristics of organic molecules. The majority of the students in the study translated between several representations successfully, in addition to having an improved capacity to anticipate physical characteristics comprising a variety of organic molecules. These empirical works indicate that the teaching approach selected based on a student-centred approach to teaching has an overarching influence on the learning of chemistry, particularly organic chemistry, on students' academic achievement. Although many different student-centred instructional approaches have been used over the decades to remediate these difficulties encountered by SHS science students in Ghana, from related literature, it is obvious that the difficulties reported in Organic chemistry knowledge at the conceptual level are persisting. There is, therefore, a need for further investigations into the existing problems in the instruction and study of organic chemistry to address the challenges that have been reported.

Statement of the Problem

The mastery of skills in organic chemistry in nexus with other science-related subjects has the propensity to enhance the competitiveness of a country’s manufacturing sector and technical expertise. Nevertheless, the curriculum for organic chemistry often consists of theoretical principles that serve as the foundation for subsequent academic pursuits in the field of chemistry and related scientific disciplines. According to Taber (2002), a comprehensive understanding of the topic is contingent upon the appropriate conceptualisation of these fundamental notions. This assertion to a more considerable extent contributes to the perception held by students about the learning of science and the belief that learning organic chemistry is very challenging (Johnstone, 2010; O'Dwyer & Childs, 2017; Woldeamanuel, Atagana & Engida, 2014). Over the decades, SHS chemistry students in Ghana have exhibited challenges in acquiring a conceptual understanding of organic chemistry. Analysis of the West African Examinations Council (WAEC) chemistry examiner's reports in the past 10 years have indicated that students studying chemistry encounter challenges when it comes to effectively showcasing their grasp of key concepts in organic chemistry, particularly in relation to hydrocarbons (WAEC, 2011; 2012; 2013; 2014; 2016; 2017; 2018; 2019; 2020; 2021).

In 2011, most candidates failed to give the major product(s) formed in the reactions between ethene and acidified water at high temperatures. In 2012, most candidates could not draw the appropriate diagram to explain the formation of a C=C double bond in an alkene. In 2013, the majority of the students could not specify the reagents needed to convert $CH_3CH = CH_2$ to $CH_3CH_2CH_2OH$. Also, in 2012 and 2016, most of the students defined isomerism as a compound and isomer, respectively, instead of a phenomenon. In 2014, the majority of students were unable to identify the type of reaction that benzene undergoes, including those who confused it for an unsaturated compound due to Kekule's structure and erroneously mentioned addition reaction. In 2016 and 2017, some candidates were unable to draw and name the complete structures of an alkene isomer with the molecular formula C_4H_8. In 2020, a significant proportion of students demonstrated an inability to correctly identify the industrial origin of benzene. In 2021, most candidates failed to explain why alkenes are described as electrophilic addition reactions.

Also, the students exhibited difficulties in conceptual understanding in responding to questions bordering on functional groups (WAEC, 2011; 2012; 2013; 2015; 2018; 2019; 2020; 2021). In 2011, most candidates failed to give reasons for classifying organic compounds based on functional groups. A significant proportion of the students demonstrated an inability to ascertain the major product(s) formed in the reaction between ethanol and iodine in the presence of $NaOH_{(aq)}$ at high temperatures. In 2012, candidates could not explain the difference observed in boiling points of the two isomers C_2H_5OH and $CH_3{-}O{-}CH_3$, and could not also draw the structures of $CH_3CH(NH_2)COOH$ in an alkaline medium and at an isoelectric point. In 2013, a few of the candidates could specify the reagents needed to convert $CH_3CH_2CH_2\text{-}OH$ to CH_3CH_2COOH and CH_3CH_2COOH to $CH_3CH_3COOCH_3$, respectively. In 2015, the majority of the candidates could not name or draw the structure of ethanol. Furthermore, a significant majority of the candidates exhibited an inability to accurately compose the chemical equation or name the resulting products of the chemical reaction involving ethanol and ethanoic acid. Few of the candidates who were able to write the chemical equation could not also show the reversibility sign. In 2018, most of the candidates failed to define a functional group in relation to an organic compound. Further, the majority of the candidates were unable to draw the structural formulas of 3-chloro-3-methylbutan-2-ol and 3-methylbutanoic acid. In 2019, only about 10% of the students who attempted the question on functional groups did well. Majority of the candidates could not draw the structure of 2-aminoethanoic acid as they failed to show all the bonds and atoms in the compound. Further, most of the students could not identify the functional groups in 2-

aminoethanoic acid. Also, most of the candidates could not name the product obtained when two molecules of 2-aminoethanoic acid combine, failing to name the type of reaction it undergoes. In 2020, majority of the students were able to arrange ethanol, ethane, and butane in correct order of increasing boiling points; however, they could not provide explanation or reasons for their answer. Also, the vast majority of the candidates were unable to identify the class of organic compounds that could be detected by ammoniacal silver trioxonitrate$_{(V)}$ solution. In 2021, majority of the students failed to explain why chloroethanoic acid is a stronger acid than ethanoic acid. Further, most candidates failed to identify amongst C_3H_7OH, C_2H_2, CH_3COOH, C_3H_6, and $C_{17}H_{36}$ the compound that can undergo substitution reaction.

The persistent difficulties in the conceptual understanding of science students in organic chemistry have been attributed to several factors. However, most reports consider the inappropriate instructional approaches employed in the organic chemistry lessons by teachers as the major contributing factor to students' conceptual difficulties and their low achievement in organic chemistry (Barkar, Zain & Hisham, 2012; Bodner, 2003; Gafoor & Shilna, 2013; Hanson, 2017). Exploring further the difficulties that exist in organic chemistry instruction and learning, among science students in the SHS in Ghana was important for the development of instructional strategies so as to improve on teaching and learning organic chemistry.

Purpose of the Study

The overall goal of the study was to improve teaching and learning of organic chemistry in senior high schools. The study specifically looked at;

1. explore the barriers and opportunities of teaching and learning organic chemistry amongst science students in the SHS.
2. explore the development of an intervention that can be used to improve teaching and learning organic chemistry in the SHS.
3. examine how the instructional tool will impact students' conceptual understanding of organic chemistry in the SHS.
4. examine students' perceptions and experiences of the use of the instructional tool in teaching and learning organic chemistry in the SHS?

Research Questions

The following research questions guided the study:

1. What are the identifiable barriers and opportunities of teaching and learning organic chemistry amongst science students in the SHS?
2. What instructional strategy can be designed to improve teaching and learning organic chemistry amongst SHS science students?
3. How does the instructional strategy in its primary purpose facilitate the conceptual understanding of organic chemistry amongst science students in the SHS?
4. How do students perceive and experience the use of the instructional strategy in teaching and learning organic chemistry amongst SHS science students?

Significance of the Study

The anticipated outcome is expected to adequately inform stakeholders including chemistry teachers, educational institutions, curriculum and instructional planners, and the MOE on the various barriers and opportunities for teaching and learning organic chemistry. This will help stakeholders in chemistry education to institute measures by providing the necessary support to eliminate the identified impediments at the SHS level.

The instructional strategy designed would be beneficial to both teachers and students during organic chemistry lessons. The conclusions of the study are hoped to enhance and facilitate science teachers' pedagogical activities by engaging students during organic chemistry lessons and individual needs of the students, thereby facilitating, and entrenching the student-centred approach to instruction. As a result, students will thus gain the ability to demonstrate a profound understanding of hydrocarbons and derived hydrocarbons in order to mentally manipulate organic structures, accurately name organic molecules, write organic reactions, and identify the distinctions in both chemical and physical properties that exist among organic compounds. Therefore, remediating the abstract nature in which organic chemistry is delivered.

Also, the outcomes on the design guidelines and the alternative instruction would contribute practically to and provide a blueprint of the processes involved in the implementation of an instructional tool to inform the policy direction of MOE and curriculum planners. The findings on improving students' performance with the alternative instructional strategy will also go a long way to impact positively on the students' conceptual comprehension and subsequently improve their performance and achievement in organic chemistry.

Further, the reflections generated from the study would be used to produce design principles and theoretical framework of the designed instructional strategy which would be of immense benefit to educational practitioners, including education technology instructional designers and researchers.

Delimitation

The study delimited itself to several parameters that focused on teaching and learning organic chemistry using a proposed instructional strategy. Though there were several SHS in Ghana, only schools in the Ashanti region were selected and subsequently used in the study because of cost-effective approach aimed at optimising data collection efforts and minimising expenditures related to sampling and data gathering. SHS 2 and SHS 3 classes were used because organic chemistry was introduced at Unit 6 in the SHS 2 chemistry curriculum, and at the SHS 3, it is expected that students exhibit some level of mastery with organic chemistry concepts.

Also, the study delimited itself to hydrocarbons at the implementation and assessment phase. This is because hydrocarbons constitute the basic building blocks of organic chemistry, which makes it essential for understanding and smooth progression to more complex concepts involving derived hydrocarbons and other organic compounds. Moreover, hydrocarbons constitute a significant portion of the SHS curriculum, therefore making it a logical starting point for introducing students to fundamental organic chemistry concepts.

Also, the design-based research framework was replete with different models that could be employed, but in this study, Reeve's (2006) model was utilised. The selection of Reeves' (2006) four-phase model of DBR was based on its suitability and explicit consideration of educational technology and its capabilities.

Limitations

In this study, a single group pre- and post-test quasi experimental design was adopted which incorporated both quantitative (questionnaire, pre- and post-tests) and qualitative evidence (semi-structured interviews, exit cards). While the inherent errors and constraints of each data gathering method used might potentially alter the overall findings and interpretations of the study, triangulating the results from these methods bolstered trust in the findings.

The quasi-experimental single group pre- and post-test design allowed for the utilisation of an intact class as participants in the current investigation. Therefore, it is not viable to generalise the findings about the improvement of students' conceptual understanding of organic chemistry to all SHS students in Ghana.

Definition of terms

ASSURE: Analyse Learners, State Objectives, Select Methods, Media, and Materials, Utilize Media and Materials, Require Learner Participation, Evaluate and Revise.

ADDIE: Analysis, Design, Development, Implementation, and Evaluation.

TPACK-IDDIRA: Technological Pedagogical Content Knowledge – Integrating Digital Devices into the Real-time Assessment.
RCET: Research Centre for Educational Technology.
ARCS Model: Attention, Relevance, Confidence, and Satisfaction Model.
ADAPT: Analyse, Design, Assess, Prototype, and Test.
Successive Approximation Model: An iterative design and development process often used in instructional design, particularly in the context of software and e-learning development.

Organization of the Study

The thesis was organised into five chapters. The chapters were logically organised following the Chapter One to look at the insight and the rationale of the study collecting data to help answer the research questions.

The second chapter, Chapter Two, covered the literature review in which reports of similar studies, and theories underpinning the learning of organic chemistry were discussed. The areas of review were teaching and learning organic chemistry, chemistry students' conceptual understanding of organic chemistry, and access to teaching and learning resources.

Chapter Three provided an overview of the technique utilised in the investigation. The methodology comprised the following components: research design, population, sample, and sampling procedure. The remaining aspects comprised the research instrument types, procedures for validating and ensuring their reliability, data collection methods, and data processing and analysis techniques.

In Chapter Four, the collected data were presented and analysed by some statistical and thematic procedures, and the results presented in tabular and diagrammatic forms. The findings from the presentation of the results were discussed in line with the stated research questions.

Lastly, Chapter Five provided a summary of the findings with their corresponding recommendation for improving teaching and learning organic chemistry amongst SHS chemistry students in Ghana. Conclusions for the study were drawn and presented in this chapter.

CHAPTER TWO

LITERATURE REVIEW

This section outlines the literature that was reviewed in developing the theoretical underpinnings of this research. The purpose of this research is to offer a comprehensive analysis of the core challenges in relation to the instruction and acquisition of knowledge in the field of organic chemistry. The areas of review will include students' conceptions; constructivism, challenges in learning organic chemistry; students' attitude towards learning organic chemistry; instructional design; sources of conceptual difficulties in organic chemistry; and theoretical design framework. The remainder of the review will aim to investigate design-based research, and the rationale for the choice of instructional design identified to develop an instructional procedure in instruction and learning organic chemistry. The review will be carried out to demonstrate the justification of how the research is firmly anchored in literature and its role in informing certain judgements made throughout the investigation.

Students' Conceptions

Conceptions are students' understandings or beliefs about what something is or should be. According to Martin, Sexton, and Gerlovich (2002), students' conceptions refer to the conceptual frameworks that individuals develop based on their personal experiences, which may contain inaccuracies or misconceptions about various ideas, objects, or events. The conceptions held by students may be seen as personal interpretations that arise from their direct or indirect experiences with a particular phenomenon. These interpretations may diverge from the explanations accepted by the scientific community (Entwistle, 2007). According to Wandersee, Mintez, and Novak (1994), it has been shown that students had diverse preconceived notions on natural phenomena and objects within the domains of physics, biology, environmental science, chemistry, and related disciplines before they start their formal scientific education. The assumptions of these students are shaped by several variables, including as peer culture, language, explanations provided by instructors, and instructional resources (Mupa, Chinooneka & Masvingo, 2015).

The presence of numerous challenges among students in science classrooms, such as age, ability, gender, and cultural differences, might hinder the effectiveness of novel teaching and learning approaches (Amin, Smith & Wiser, 2014). The convergence of students' pre-existing knowledge with novel material presented in the context of science instruction gives rise to a variety of unanticipated learning outcomes. Hence, it is evident that diverse students may arrive to varying conclusions, while sharing comparable experiences and classroom observations (Aufschnaiter & Rogge, 2010). Students' conceptions have been observed to be resilient and hard to shift to scientific conceptions through the passive process as students require appropriate support, such as student-centred teaching and learning methods, to nurture and promote any potential change (Vosniadou, 2007). The impact of teaching strategies on students' perceptions of organic molecule structures in the field of chemistry is well acknowledged. The limited availability of frameworks for comprehending abstract ideas such as molecular structures stems from the learners' reliance on their prior scientific knowledge (Taber, 2001). According to Uce and Ceyhan (2019), students in the field of chemistry often develop conceptions that differ from the intended concepts to be learnt. These alternative conceptions might have an impact on their future learning experiences. For instance, Adesoji and Omilani (2012) conducted a study which revealed that students' interpretations of ideas connected to inorganic analysis, both quantitatively and qualitatively do not align entirely with scientific principles. According to Adesoji and Omilani (2012), a limited number of students possess the capacity to take part in symbolic level of learning, which is considered to be the most closely aligned with meaningful learning.

Students' perceptions of thermodynamics were investigated in 8th graders, high school students, undergraduates, and a cluster of ‘experts’ with advanced degree in many fields have been researched (Lewis & Linn, 1994). Lewis and Linn discovered that both high school and university students all had similar views on the natural world. Students' perceptions were significantly lower just amongst Ph.D. students. The explanation for this could be that the majority of the students hold ideas that are opposed to what they have been taught. Students' conceptions of chemistry, particularly organic chemistry, may be so resistant to training that a considerable portion of the population, even after being taught, continues to retain them, or fails to put their knowledge to work to resolve issues (Cormier & Voisard, 2018; Lewis & Linn, 1994).

Lythcott (1990) asserts that problem-solving is commonly seen as the practical application of acquired information. However, it is argued that this assumption is flawed. When it comes to organic chemistry, it is common for students to acquire a proficient ability to solve problems and arrive at accurate solutions, often without fully comprehending the underlying concepts that the questions aim to evaluate. In their study, Mulford and Robinson (2002) observed that a significant number of college students who demonstrated proficiency in solving algorithmic puzzles exhibited a limited comprehension of the underlying principles of chemistry. In other words, it is possible for students to get an A grade while still harbouring several misunderstandings. Additionally, although there were statistically significant improvements in their understanding of concepts, the instructional significance of these advances remains uncertain. In their study, Bhattacharyya and Bonder (2005) found that students with excellent problem-solving abilities in organic chemistry displayed notably low levels of conceptual comprehension. This lack of understanding was mostly attributed to a learning style centred on memorising.

Similarly, Celikkıran (2020) discovered that while practically all high school students studying chemistry were capable of balancing equations, which is considered a purely algorithmic task, more than half were unable to create precise chemical diagrams to describe the outcome. There are not enough relational structures to grasp how to build molecular diagrams. Ausubel (2000) refers to relational structures as advance organisers. According to Adesoji and Omilani (2012), principles that make up a subject matter have a relational structure that determines the order in which they are acquired. Understanding the IUPAC naming rule for organic molecular structures, using oxidation numbers of elements in creating molecule graphic structures, and hybridisation of carbon atoms, for example, are related structures to understanding organic molecular structures and organic chemistry. As a result, any instructional activity that facilitates conceptual change must be precisely sequenced.

Beginning organic chemistry students often lack the fundamental information required to construct an organic molecule structure (Rice, 2016). Rice contends that when given the formula C_2H_6O, for instance, students have numerous options for arranging the atoms. According to Rice, the likelihood of students successfully devising the appropriate arrangement is low unless they had already engaged in the act of drawing or seen a comparable example. This may be because the instructional process itself frequently omits or obscures fundamental requirements for meaningful learning of the structures. It should also be noted that the majority of chemistry instructors assume that their students comprehend the molecular structures and can draw them (Springer, 2014), so the teachers may devote little time to the activity of drawing these structures.

According to Kind (2004), and affirmed by Visser (2017), since students cannot readily unlearn notions, it is imperative for teachers to instruct students on the desired knowledge of chemistry from the beginning. There is a common belief among students that the backbone or parent carbon atoms of a molecule must be arranged in a linear, horizontal fashion, and that the numbering of carbon atoms in any given structure should start from a single side. Furthermore, it has been observed that the identification and naming of compounds often neglects the consideration of functional groups, substituents, and branches (Adu-Gyamfi, Ampiah, & Appiah, 2017; see also Stull, Hegarty, Dixon, & Stieff, 2012; Treagust, Chittleborough & Mamiala, 2004). In addition, the students inappropriately applied the octet rule and drew inaccurate structural representations by incorporating an excessive number of carbon atoms in the molecular structure of a specific compound (Kind, 2004; see also Salame, Patel & Suleman, 2019; Sandi-Urena, Lora, & Jinesta, 2019; Sarkodie & Adu-Gyamfi, 2015).

Constructivism

Although constructivism has become more well-known recently, its historical roots may be traced back to the era of Socrates, who advocated for the facilitation of communication, interpretation, and construction of latent knowledge between educators and learners via the use of questioning techniques (Hilav as cited in Erdem, 2001). In addition, Gruber and Voneche (1977) argue that Piaget's (1967) constructivist perspectives and Bruner's (1996) constructivist depiction of discovery-based learning are likely where the idea of constructivism originated. Perkins (1992) highlights that constructivism draws upon several foundations in 20th-century psychology and philosophy, including Piaget and Inhelder's (1969) developmental viewpoint and the rise of cognitive psychology led by influential thinkers like Bruner (1966).

Constructivism's concepts and definition: Constructivism is regarded as a theoretical framework that encompasses several aspects, including learning, knowledge, and pedagogy. It is characterised by its role as a theory that is subservient to the intrinsic processes of education, development, and learning. It uncovers and demonstrates educational realities that traditional theories are unable to convey or emphasise (Amineh & Asl, 2015; Bada, 2015), Constructivist theory can therefore be described as a mode of learning and cognition where learners interact with their environment to solve problems (Shah, 2019). Also, "this learning theory is predicated on the idea that students actively construct knowledge, which necessitates a dramatic reduction of reliance on a didactic, textbook-based, knowledge transmission approach to teaching and learning in the classroom" (Prawat, 2008, p. 182). As such, it assists teachers in taking into account students' prior knowledge, encouraging their continuous learning efforts, and enabling students to apply knowledge in real-world situations.

Conceptualised from a psychological and philosophical stance, constructivism asserts that much of what we learn and understand is formed or constructed by individuals (Bruning et al., 2004). According to Driscoll (2000), the concept of constructivism posits that knowledge is confined solely inside the cognitive processes of individuals. Hence, students persistently endeavour to develop their cognitive frameworks of the tangible world. Individuals produce fresh knowledge on which to base their understanding of reality by continually upgrading their models. Savenye and Robinson (1996) believe that constructivism serves to stimulate and nurture learners' inherent inquisitiveness regarding life and the surrounding environment. Over time, the students undergo a transformation into proactive learners, actively participating in this learning process by using their past experiences, existing knowledge, and real-world contexts. This approach fosters the development of skills such as making informed assumptions, validating hypotheses, and formulating well-grounded conclusions.

The significance of constructivism is growing in tandem with the ongoing advancement and evolution of education. Consequently, it assumes a pivotal role as a theoretical underpinning that warrants careful consideration during preparation and implementation of educational programmes. The constructivist indicator posits that information is not acquired in its complete form, but rather is gradually constructed upon pre-existing knowledge, resulting in the development of new knowledge (Pereira & Sithole, 2020).

Moreover, constructivism is a widely acknowledged educational theory that promotes participation of students in the procedure of understanding and collectively constructing the meaning of reality and its social dimensions. The emphasis is on knowledge development through personal experience (Maksimović & Milanović, 2020). The primary aim of constructivism is to get a comprehensive understanding of the cognitive skills necessary for engaging in critical thinking and collaborative activities. The construction of knowledge is contingent upon pre-existing knowledge and previous learning endeavours (Ertmer & Newby, 2013; Huang, Gao & Hsu, 2019). Constructivism's theoretical foundations depend on the systematic observation and empirical study that aims to illuminate the intricate process of learning. The constructivist learning theory posits that the human mind plays a dual role as both the generator of symbols and the medium through which genuine information is conveyed. Furthermore, this theory emphasizes the crucial role of experience in the process of discerning and constructing an individual understanding of reality. The significance of the prevailing pedagogical paradigm in relation to the advancement of pedagogy, mathematics, and science is of utmost importance, as highlighted by several scholars (Cooper, 1993; Kaufman, 2004; Srivastava & Dangwal, 2017).

To facilitate a deeper understanding of constructivism, it is necessary to compare and contrast it with behaviourism. The paradigm of behaviourism was first superseded by cognitive theory, which stresses the need of both past knowledge and metacognitive techniques (Maksimović & Milanović, 2020). According to Maksimović and Milanović, behaviourism, which was widely adopted by educators as an implicit learning theory to shape instructional curricula, was ultimately superseded by constructivism. This shift occurred because constructivism was seen more effective in equipping students with the necessary skills and knowledge for their future professional endeavours. According to Ertmer and Newby (2013), the educational approach of constructivism requires the implementation of a curriculum that not only cultivates practical skills, but also facilitates the development of technical competencies, higher-order cognitive capacities, problem-solving skills, and collaborative learning capabilities. In contrast to the behaviourist perspective, constructivism posits that the process of knowledge construction is dynamic, with active student engagement and a recognition of the significance of both individual and social experiences. Furthermore, constructivism acknowledges that the resulting knowledge will exhibit varying degrees of validity as a reflection of reality (Brau, 2018). In contrast, the behavioural learning theory involves the process of breaking down tasks into smaller segments or subtasks and integrating practical activities to acquire experience through feedback (Kanselaar, 2002). The objectivist epistemology of behaviourism and the idea of learning based on information processing inspired the development of the constructivist paradigm. Learning theories such as constructivism, behaviourism, and cognitivism are all influential in developing teaching practises (Ertmer & Newby, 2013). The educational philosophy of constructivism emphasizes that students actively engage with their environment to gain information, generate new ideas, and ascribe significance to various events. This approach contrasts with traditional methods of passive learning, where students passively receive pre-determined meanings without active involvement (Kanselaar, 2002).

Constructivist perspective on learning: The Constructivist philosophy is known for its emphasis on promoting, motivating, and facilitating learning via activities such as work, cooperation, research, and discussion (Ertmer & Newby, 2013; Shah, 2019). The student serves as a partner, while the teacher serves as a motivator in which student involvement is mandatory in the process of knowledge construction. According to Pereira and Sithole (2019), the student assumes a central role in the learning process. It is predicated on the premise that learning is a psychological construct (Narayan, Rodriguez, Araujo, Shaqlaih & Moss, 2013) to understand entail, the capacity to modify, transform, and comprehend the transformation process and its constituents. Where students' prior knowledge and experiences are supplemented with new facts. In contrast to the passive transmission of information, constructivist learning emphasises the importance of the student in generating new knowledge (Anthony, 1996; Bada, 2015; Lin, Huang & Hsu, 2019; Piaget 1964). In order to ensure that knowledge production and reconstruction are relevant and advantageous for the student, it is imperative to use a targeted and thorough approach while engaging with teaching and learning materials (Gray, 1997).

In his work, Taber (2006) examines the fundamental and pivotal principles that characterise constructivist learning.

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1. Students construct knowledge on their own; they do not absorb facts that are imposed on them.
2. The phenomena are inextricably linked to pre-existing concepts and knowledge.
3. Students' worldviews are culturally and socially accepted and serve as the foundation for comprehending a variety of phenomena and processes.
4. Certain ideas may conflict with widely accepted scientific concepts, while others may be difficult to change or reconstruct.
5. Knowledge is a conceptual structure that is located in the brain and can be described in detail.
6. Students' ideas in class must be taken seriously if we wish to influence them and motivate them to improve.
7. While knowledge is intrinsically personal, it is constructed through interaction with the environment and collaboration with others" (p. 125-184).

The constructivist learning process begins by establishing fundamental concepts and then progresses towards more intricate ones with the intention of developing students' abilities to actively engage in the learning process and promote collaborative relationships with their peers (Maksimović & Milanović, 2020). Acquiring knowledge and skills is a dynamic and continuing procedure through which individuals cultivate their own unique understanding and interpretation of the world (Cilliers, 2017). The construction of knowledge is facilitated by prior experiences, which prioritize problem-solving and understanding. Additionally, the acquisition of knowledge is enhanced via engagement in genuine activities, collaborative experiences, and comprehensive examination of all elements that influence the learning process (Lin, Hwang & Hsu, 2019; Christie, 2005). Based on the constructivist idea, learning is conceptualized as an active process wherein students autonomously participate, as opposed to passively acquiring and memorising knowledge. According to Hoover (1996), students acquire comprehension and assimilate material by utilising their pre-existing knowledge. Yilmaz (2019) posits that within a constructivist learning environment, the acquisition of information is an active undertaking whereby students engage in the assimilation of their experiences during the process of acquiring new knowledge, while simultaneously integrating their existing understanding and past knowledge. Within this particular context, the sequential stages that outline the process of constructive learning might be explicated as follows: The process of acquiring knowledge involves the student and instructor engagement in the learning process. The teacher assumes a leadership role, while the authority is shared between the teacher and the student. According to Tam (2000), an optimal class size should be restricted to a small group of students from a wide range of backgrounds and skills.

The articulation of elements contributing to the efficacy of constructivist learning has been influenced by the consensus reached on general constructivist ideas and practices. (Bada, 2015; Doolittle & Camp, 2019) identified several key elements that contribute to effective learning environments. These elements include the provision of authentic and real-world learning experiences, the incorporation of social interactions and mediation throughout learning procedure, application of pertinent content that can be easily connected to the learner's existing knowledge, the implementation of formative student assessment practices, the cultivation of student self-awareness, and the role of teachers as facilitators who offer diverse perspectives. According to Matar (2018), an examination of constructivist theory reveals the existence of five distinct categories of learning. These elements can be described as being situated, active, experiencing, educational, and authentic. Situated learning places considerable emphasis on the pivotal function of context and interaction in the process of constructing knowledge. The cognitive process is distinguished by the constructive and cognitive interactions that occur between individuals and things and events. Knowledge is derived from the collective efforts of students, both in their personal pursuits and via their interactions with others. The process of learning encompasses the assimilation of cultural influences and the engagement in social exchanges.

Active learning, as a second kind of learning, places focus on the learner's engagement and posits that learning is an interactive procedure including the building of knowledge via effort, rather than a passive reception of information (Maksimović & Milanović, 2020). Experiential learning emphasises the importance of the student's personal experience. Instructional learning emerged as a consequence of an examination of situated learning, leading to the development of instructional perception. In contrast, authentic learning emphasizes the importance of designing the learning context, assignments, activities, and evaluation in a manner that closely aligns with real-world scenarios, hence enhancing the transfer of information from formal education to practical application. Authentic learning means the educational approach that emphasises the involvement of students in authentic, real-world situations. In this setting, students are given opportunities to evaluate ideas and provide solutions, make mistakes, and correct them, and engage in successive iterations of their learning process (Matar, 2018; Pereira & Sithole, 2020). Educators who use a constructivist pedagogical approach engage students by presenting them with inquiries and challenges, guiding them in the process of exploring and generating their own responses and resolutions. Srivastava and Dangwal (2017, p. 775) suggest the following effective learning techniques: "

1 Students are capable of independently formulating questions.
2 Multiple intelligences - enables students to create a variety of interpretations and expressions of their learning.
3 Collaborative learning - students learn how to work collaboratively."

Teachers might employ the aforementioned procedures as a constructivist pedagogical framework, wherein both the teacher and the learner assume equitable roles as active contributors to the educational journey. This approach entails a range of tasks and obligations for each party, ultimately leading to substantial advancements and accomplishments.

Variations on constructivism-based theories of learning: Constructivism is distinguished from behaviourism and cognitivism by its underlying postulates and goals (Ertmer & Newby, 2013). The key tenet of the constructivist learning model is the generation of knowledge through personal experience and its subsequent application to new learning (Bada, 2015;

Cooper, 2007). The constructivist theory encompasses a set of assumptions and notions that may be concisely summarised as follows: “

1. Emphasis is placed on understanding the context in which certain skills will be acquired and then applied (learning should be based on meaningful contexts),
2. Emphasis is placed on developing students' control and their ability to manage information (active use of the learned concepts),
3. The necessity of presenting information in a variety of ways (reconsidering learning content at different times, under different contexts, for different purposes and different conceptual perspectives),
4. Support for the development of problem-solving abilities that enable students to progress (development of pattern recognition skills),
5. Assessment of acquired knowledge and skills (presenting new situations that differ from the initial instruction).
6. Knowledge is actively constructed and belongs to the student; the child constructs knowledge through his or her activities and does not simply accept pre-existing knowledge, but rather shapes his or her view of the world.
7. Children's acquired ideas and knowledge become meaningful when they are integrated with pre-existing knowledge.
8. There is no such thing as a universal reality; rather, there are numerous individual interpretations of the world.
9. Students participate in discovery and invention in a constructivist classroom through explanation, negotiation, and discussion.”

(Clements & Battista, 1990, p. 50-72; Ertmer & Newby, 2013, pp. 34-35)

As an educational philosophy, the constructivist approach to learning incorporates the following theories: “situated cognition theory,” “activity theory,” “experiential learning,” and “instructive and authentic learning” (Mattar, 2018). Mattar proposed a categorisation of constructivism into four distinct perspectives: “cognitive constructivism,” “radical constructivism,” “situational constructivism,” and “co-constructivism.” The formulation of constructivism into four categories was derived by weighing the core principles with respect to constructivism and attempting to organise them based on parallel dimensions: the objective/subjective perception of reality and the social/individual knowledge building. The four schools of constructivism exhibit a number of shared beliefs. These include the notion that learning is an active rather than passive process, recognising the critical role of language in the learning journey, advocating for student-centred environments, and emphasising the importance of focusing on the process of education rather than solely on content. Consequently, educators must possess a profound familiarity with their students to effectively structure and facilitate this process (Maksimović & Milanović, 2020). The diverse range of techniques and interpretations of constructivist theory has led to the emergence of numerous conceptualisations and subcategories within the constructivist framework.

Vadeboncoeur (2005) examines the concept of constructivism from three distinct approaches. Regarding constructivism's subtypes, Kanselaar (2002); and Santrock (2001) believe that there are two subtypes:

constructivism and socio-constructivism. According to a range of researchers (Creswell & Creswell, 2009; Dollitle & Camp, 1999; Kanselaar, 2002; McKinley, 2015; Milutinovic, 2015; Pereira & Sithole, 2020; Yilmaz, 2019), a significant differentiation that aids in the comprehension and articulation of constructivism is the categorization into “social,” “radical,” and “cognitive” constructivism.

By outlining the zone of proximal development, Vygotsky founded the school of thought known as social constructivism. According to Srivastava and Dangwal (2017), this idea suggests that students can effectively tackle challenges that is beyond their existing capacities by participating in collaborative activities with peers who possess superior skills and capabilities. The constructivist approach discussed in this study places significant focus on the social aspect of human development and acknowledges that knowledge is formed via interpersonal interactions (Candra & Renawati, 2020). Social constructivism is a theoretical framework situated within the constructivist paradigm, which asserts that student participation has an important function as agents in the process of generating meaning. The perspective emphasizes the role of students in actively engaging with their learning environment, leading to enhanced levels of reasoning, and learning outcomes (Powell & Kalina, 2009). This concept functions as the theoretical underpinning for qualitative research and as a means of understanding how humans engage with their environment (Cilliers, 2017; Gayle, 2005). From constructivist view point it is the meeting point between cognitive constructivists' known reality and radical constructivists' construction of a personal and coherent reality (Doolittle & Camp, 1999). The researchers suggest that, conversely, social constructivism places emphasis on the collaborative development of meanings within social activities, prioritizing the significance of meaning over structure.

Cognitive constructivism is closely related to information processing and is predominately concerned with the cognitive process (Schunk, 2012). Considered a structuralist view of learning (Bruner, 1966; Piaget, 1970; 1976), it describes how a student gains knowledge of the world through a progression of conceptual shifts. According to Gruber (1995), the best classrooms are those that encourage students to actively engage with one another and with their teachers, and that have sequential, recursive activities that help students acquire and apply information and skills through introspective application. Knowledge is derived through the process of accurately internalizing and reconstructing an external reality (Doolittle & Camp, 1999). This process leads to the development of cognitive processes and structures that align with real-world processes and structures. The constructivist approach, as discussed by Ertmer and Newby (2013), is often criticized for its perceived lack of robustness when compared to learning or development theories. These alternative theories propose that individuals play an active role in constructing meanings and phenomena, with these constructs being influenced by their unique perspectives and partially shaped by their existing knowledge.

According to the theoretical underpinnings for radical constructivism, it is argued that individuals do not possess direct awareness of an external world. Instead, students actively engage as they work to build their own understanding which encompasses a broad spectrum spanning from ordinary observations to scientific understanding. Radical constructivism is a non-traditional perspective that addresses the challenges associated with the acquisition and manifestation of knowledge (Taylor, Fraser & Fisher, 1997). The theory of knowledge being discussed challenges the conventional philosophical perspective of realism, which asserts that knowledge must accurately represent an objective world. Instead, it advocates for a relativistic understanding of knowledge (von Glasersfeld, 1995). Based on this concept, knowledge is formed through an individual's ongoing process of understanding and adaptation (Yilmaz, 2008). The acquisition of knowledge is mostly derived from personal experiences rather than being a direct representation of an external reality. This perspective aligns with the concept of constructivism, which emphasizes the active development of mental structures by individuals (Dollitle & Camp, 1999; Glasersfeld, 1995; Kansellar, 2002; Yilmaz, 2008). In contrast to cognitive constructivism, which primarily emphasizes structure, radical constructivism encompasses the incorporation of meaning (Brau, 2018).

A constructivist perspective on teaching: Prawat (1992) argues that most accounts of constructivist theory share an understanding that it requires a radical transformation in how we approach education, with students' efforts at comprehension taking centre stage. Learning, as described by Gray (1997), takes place when students actively contribute to the production of meaning and knowledge. Constructivist teaching is a simple method that boosts students' motivation, critical thinking, and autonomy in the classroom. According to Hoover (1996), constructivism has far-reaching consequences for education. One cannot just transmit one's own level of understanding to another, from someone more knowledgeable to someone less so. When it comes to teaching, constructivists are more than just "new lesson presenters" who deliver a canned speech. Instead, constructivist instructors serve as mentors, prompting students to evaluate whether or not their knowledge is sufficient. Second, constructivist educators take into account students' past knowledge and create learning settings that make use of gaps between students' existing and new information (Hoover, 1996). Teachers have difficulties due to the diversity of their students since they cannot all be taught using the same approach and resources. Thirdly, because constructivism values student engagement, educators should encourage active learning and highlight students' prior knowledge (Hoover, 1996). Teachers that adopt a constructivist stance are better able to tailor student educational experiences to their individual goals and interests, rather than those of the school or the school system as a whole. Hoover (1996) stresses, fourthly, the need of setting aside adequate time to proactively develop new knowledge. Students use this time to think critically about their learning and make sense of it in the context of their past experiences. When included into a constructivist classroom, bargaining connects instructors and students behind a single objective, thus enhancing learning. Bruner (1996) stresses the need of open discussion between teachers on new knowledge and limits, and Smith (1996) confirms that "customising classes daily to meet the needs of students" (p. 1).

The constructivist perspective of the teacher: Scaffolding, cognitive apprenticeship, tutoring, cooperative learning, and learning communities are all ways in which constructivist educators facilitate student learning (Rogoff, 1998). Teachers create situations within a constructivist educational setting, where students are encouraged to question their own, and one another's assumptions. As a result, a constructivist educator must create situations that call into question the assumptions underlying the foundation of conventional instruction and learning. According to the study conducted by Belenky et al. as cited in Gray (1997), individuals at the constructivist stage of cognition engage in a continuous process of reassessing their assumptions regarding knowledge. Their perspective towards authority figures, commonly referred to as "the expert," undergoes a transformation. Furthermore, they exhibit a comfortable disposition towards ambiguity and are drawn to intricate and intricate situations. Lastly, they embark on an unending pursuit of truth and knowledge, perceiving truth as a dynamic process in which the individual actively participates. Within the educational setting, a constructivist educator's understanding of expertise is derived from the discussion amongst students and between students and teacher. Moreover, such a teacher has a notable inclination towards embracing a lack of clarity, as evidenced by their natural inclination to encourage complexity. The research of Lester and Onore (1990) suggests that the significance of teachers' personal views towards teaching, often known as their construct systems, lies in their ability to shape the nature and magnitude of changes they may implement. Furthermore, Lester and Onore believe that educators perceive instruction and events via the framework of their construct system. The primary factor that impacts a teachers' capacity to instruct in a "transactional," constructivist approach is the conviction that individuals actively create knowledge. Furthermore, in order to effectively revolutionise their teaching practises, educators must undergo a fundamental change in their cognitive framework and modify their epistemological convictions towards knowledge. Mezirow (quoted in Gray, 1997) asserts that engaging in reflective practise enables instructors to undergo a transformative process in their cognitive and belief systems towards teaching. This facilitates the teacher's change from a common transmission conventional teaching methods in favour of constructivist and transactional pedagogies. According to Lester and Onore (1990), the adoption of a constructivist viewpoint on knowledge allows educators to engage in experimentation and the generation of innovative concepts pertaining to pedagogy and the acquisition of information. Nevertheless, it is crucial to give more consideration to the teacher's role in advocating for this perspective, while considering several factors that influence the act of teaching, including the prevailing educational system, its regulations, and the overall school culture. One instance illustrating the impact of constructivism on pedagogy can be found in the work of Carpenter and Fennema (1992). In their cognitively guided Instruction (CGI) mathematics programme, they observed that elementary school teachers underwent comprehensive training in constructivist approaches, including the utilisation of intricate problems, modelling techniques, collaborative problem-solving activities, and the instruction of metacognitive strategies. As a result, these teachers witnessed enhancements in their students' cognitive abilities, particularly in higher-order thinking skills, and observed improved performance on conventional assessment measures such as compass tests. In addition to the favourable results observed in the field of scientific education through the application of constructivist principles (Neale, Smith & Johnson, 1990), comparable achievements have also been documented in the domains of reading (Duffy, Roehler & Radcliff, 1986) and writing (Neale, Smith & Johnson, 1990).

Challenges in Learning Organic Chemistry

Many senior High School students struggle with learning and developing a conceptual understanding of chemistry because they perform poorly in the subject (Reid, 2008). According to Kamisah and Nur (2013), Fundamental chemical topics are misunderstood by students. Furthermore, many students' inaccurate scientific beliefs remain constant from elementary school through college and beyond (Sozbilir, Pinarbasi & Canpolat, 2010). Many high school students have difficulty grasping more complex concepts that build upon these more basic ones since they have not properly and adequately grasped the basics themselves (Carson & Watson, 2002; Thomas, 1997). However, most students leave their basic chemistry courses with just a minimal grasp of the subject matter (Ochs, 1996).

According to Johnstone (2000), the subject's abstract nature is the primary reason many students find chemistry difficult. Also, several researchers have categorically reported varying degrees of challenges in the study of chemistry over the years due to its complexity and abstract nature (Eilks & Hofstein, 2015; Woldeamanuel et al., 2014; Taber & Akpan, 2017). Chemistry is inherently an abstract subject because it relates to simplified, ideal samples of pure substances that are rarely encountered outside the laboratory which makes the subject fundamentally difficult (Taber & Akpan, 2017).

To illustrate the complexity of chemistry concepts, Johnstone (1991) created and presented the 'triangle of chemistry' (Taber, 2013; Talenquer, 2011), which exemplifies the correlation among the symbolic, microscopic, and macroscopic levels of thought. The central concept of the 'triangle of chemistry' is that learning chemistry requires:

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1. discussing phenomena at the level of what can be seen and touched
2. employing explanatory models that invoke conjectured entities at a scale much too small to be visible (such as electrons, ions, and molecules);
3. incorporating novel forms of representation that are part of the subject's specialized language" (Taber & Akpan, 2017, p. 326).

The ache of most learners regarding the study of organic chemistry is moving seamlessly within these three phases. As a result, the majority of students regard organic chemistry as a difficult subject (Johnstone, 2006; 2010; O'Dwyer & Childs, 2017) and almost all organic chemistry concepts at the introductory level are difficult to grasp (Childs & Sheehan, 2009; Jimoh, 2005; Johnstone, 2006; Kurbanoglu, Taskesenligil & Sozbilir, 2006; O'Dwyer & Childs, 2017). It is suggested that conceptual understanding and meaningful learning in chemistry rely on students' abilities to learn, relate, and differentiate between the microscopic, macroscopic, and symbolic levels (Johnstone. 1991; Taber, 2013; Talenquer, 2011). Understanding the nature of matter by integrating these levels and shifting between them are essential processes for a comprehensive understanding of chemistry and success in organic chemistry (Jaber & BouJaoude, 2012; Johnstone, 2000). The researchers argue that organic chemistry conceptual understanding is most likely to be a problem for students who struggle with any of these levels.

Due to a lack of cognitive ability, chemistry students at the introductory level may struggle to comprehend the abstract and complicated organic chemistry's intrinsic character, resulting in a variety of problems and misunderstandings of core organic chemistry ideas (O'Dwyer, 2012). Typically, chemistry curricula include many abstract concepts that are essential to understanding organic chemistry (Taber, 2002). These abstract concepts are crucial since additional chemistry lessons will be difficult to comprehend if students fail to comprehend these key ideas (Nakhleh, 1992; Zoller, 1990). Any difficulty students have in obtaining a comprehensive understanding of organic chemistry may result in them displaying a lack of conceptual comprehension and problem-solving ability (BonJaoude, Salloum & Abd-El Khalick, 2004; Lewis & Lewis, 2007). If students are not at the proper stage of cognitive development, they may face a slew of conceptual difficulties during their organic chemistry studies, as they may rely solely on memorisation of information rather than pursuing actual understanding (Bryan, 2007; Hassan, Hill & Reid, 2004). If students can demonstrate a conceptual understanding of the basic concepts underpinning organic chemistry, such as structural formulas, nomenclature, isomerism, physical and chemical properties, and organic reactions under both hydrocarbons and derived hydrocarbons (functional groups), they will have a true understanding of the subject. According to Shayer and Adey (1981), students need to be at an early formal level of cognitive development to exhibit a conceptual grasp of organic chemistry. Though Jean Piaget's sequencing of cognitive stages was correct, the matching age groupings were overemphasized, according to various studies (Childs & Sheedan, 2009; Shayer & Adey, 1981). According to the findings of these studies, the majority of students in the second cycle (between the ages of 12 and 15 years) have not achieved the cognitive development stage predicted by Piaget's work. The consequence could be that many students who are supposed to be at the formal operation stage are still stuck in the concrete operational stage, making fundamental organic chemistry difficult to grasp.

There exists a perspective that claims language as potentially being a greater obstacle to the acquisition of scientific understanding compared to the actual content of the subject (Gabel, 1999; Selepeng & Johnstone, 2001; Yong, 2003). The study conducted by Pyburn, Pazicni, Victor, Benassi, Elizabeth, and Tappin (2013) provides evidence indicating a favourable correlation between language comprehension ability and success in the field of general chemistry. According to Taber (2015), chemists with extensive expertise may unintentionally overlook the language proficiency of students in instructional settings, so neglecting the level of effort required to address this issue. The primary mode of conveying scientific knowledge to learners in the process of acquiring knowledge and imparting knowledge through instruction is through oral communication (Johnstone & Cassels, 1978). According to Ali and Ismail (2006), it is necessary for learners to acquire proficiency in symbol utilization for idea representation, as well as the utilization of technical or scientific language. According to Bulman (1985, p. 21), “the use of technical language in science refers to the employment of scientific terms that possess highly specific meanings, encapsulating intricate and extensive concepts that learners may not completely comprehend.” This gives rise to the challenge of unfamiliarity, as highlighted by Johnstone and Selepeng (2001). Hence, it is imperative to acknowledge the significance of vocabulary acquisition, as learners frequently have difficulties in grasping unfamiliar language (Becker & Schneider, 2004). Given the expectation for learners to demonstrate their knowledge by articulating and elucidating scientific concepts, principles, processes, laws, theories, and models (Department of Education, 2002; 2003), it is imperative for educators to offer learners the necessary opportunities to cultivate the linguistic competence needed to comprehend and employ academic language (Ali & Ismail, 2006). Consequently, learners can become acquainted with the specialized terminology essential for their academic achievement. In their study, Song and Carheden (2014) conducted a qualitative investigation to explore the comprehension of dual-meaning vocabulary (DMV) terms among college students, both before to and during chemistry teaching. The researchers discovered that (i) prior to receiving instruction, the majority of students provided definitions for DMV terms based on their colloquial understanding, (ii) following instruction, there was a notable deficiency in the retention of the scientific definitions of DMV words, and (iii) the inadequate retention of scientific meanings was attributed to factors such as limited usage, study habits, and unfamiliarity with other scientific vocabulary terms. The last aspect among these three indicates that a deficient comprehension of scientific terminology, particularly in relation to DMV terminology, might potentially amplify its impact. The utilisation of symbols in the realm of chemical communication presents some difficulties for students. When a recognised word undergoes a shift in meaning, it gives rise to a challenge in the realm of long-term memory. It is difficult for the student to establish a good mental comprehension of terminology learnt outside of the context of organic chemistry. Non-technical terminology used in science learning, according to Cassels and Johnstone (1980), is a source of misunderstanding for students. When a word is familiar but suddenly changes, Johnstone (2010) acknowledges how complicated language can cause challenges with long-term memory. Language plays an important role in the critical thinking processes required to complete any assignment. Cassels and Johnston (1985) made similar remarks, stating that language usage should be carefully considered. Language can aid or hinder long-term memory interactions, and in certain cases, can cause knowledge overload in students. This allows the learner to recognise, organise, and make sense of the data that is presented to them. According to research, students struggle more with accurately applying and interpreting words than with their perception of new, unfamiliar technical terms (Cassels & Johnstone, 1983). In the eyes and minds of students at the introductory level, a pipette is just a pipette, while a volatile molecule can indicate 'unstable', explosive', or 'flammable' (Johnstone, 1991). It is worth emphasising that it technically means "easily dissipated," something students were unaware of. Literacy and numeracy are key prerequisites for science education (Childs, 2006). In their study, Marais and Jordaan (2000) discovered that a significant number of first-year chemistry students at the tertiary level had difficulty in accurately discerning the intended definitions of fundamental elements within chemical equations. The study of chemistry requires students to acquire a distinct and unfamiliar vocabulary. The Periodic Table is akin to a chemistry alphabet. Before students can write chemical formulas, they must first be taught and understood. To balance and interpret chemical equations, proper language and punctuation must be acquired. A clear comprehension of the International Union of Applied Chemistry (IUPC) nomenclature regulations is one example. Students who grasp these criteria should be able to recognise, classify, and systematically name organic compounds, as well as identify and draw organic compounds from IUPAC names. Also, to comprehend how the organic compounds will react with each other, students should be able to recognise the names of functional groups and substituents. However, students have challenges in understanding this vocabulary as reported in a study by Vladusic, Bucat, and Ozic (2016). According to their findings, it was observed that students encounter difficulties in comprehending the definitions of scientific terminology, symbolic representations, and common vocabulary employed in the instruction and acquisition of chemistry knowledge. Notably, there were notable variations in the level of comprehension exhibited by students, both across different words and symbols.

Another stumbling block to the learning organic chemistry is the limited capacity of working memory (Baddeley, 1999; Hussein & Reid, 2009). This limited shared space connects what has to be preserved in conscious memory with the cognitive operations required to handle, convert, alter, and prepare information for long-term memory storage. Students' memory capacity differs in terms of how much information they can store in a given amount of time (Johnstone, 2000). Students have trouble comprehending vital information from others when they are faced with learning scenarios that place a heavy demand on their limited memory space. We should foster students' ability to understand organic concepts so that working memory space is not overloaded, causing other crucial information to be processed and interpreted as noise (Cowan, 2014). Unless this is accomplished, students will rely on rote learning, which does not transform into conceptual understanding. When learners are presented with too much information to handle in a restricted working space, they struggle to distinguish the significant information from the less important information. The latter has been labelled 'noise', with the learner having trouble distinguishing between the signal and the noise (Johnstone, 1991).

The correlation between working memory capacity and challenges in conceptual comprehension and academic performance has been shown in previous research (Johnstone & Kellett, 1980). The working memory region serves two purposes: temporary storing of incoming information and processing and making sense of the data. Information presented in an inaccessible manner presents a larger difficulty for conceptualization since the learner's working memory space is constrained, overloaded, and eventually fails to operate. Information overload and restricted working memory space have been discovered to be the root of much of the difficulty in science and chemistry (Johnstone, 1991). Learning and understanding abstract concepts are doable for learners with smaller working memory spaces if effective teaching tactics are used (Danili & Reid, 2006; Johnstone, 2006). Surprisingly, most beginning chemistry textbooks and syllabuses are dense with new concepts that students are expected to grasp in a short period (Tsaparlis, Pappa & Byers, 2018). An in-depth examination of the SHS chemistry syllabus reveals that the students will be exposed to a large number of new concepts. It is not surprising that when studying organic chemistry, a student's working memory area might quickly become overburdened. Knowledge overload was defined by Bawden and Robinson (2020) as the number of pieces of information that a non-expert learner may hold while completing a task satisfactorily at the same time. As a result, the complicated nature of chemistry, which necessitates multi-level thinking, may greatly contribute to the overload of SHS chemistry students' working memory space.

Students' Attitude towards Learning Organic Chemistry

The question of attitude has been thoroughly defined and investigated by scientists on a global scale. In conclusion, the attitude towards science is determined by an individual's values, feelings, and beliefs towards the field of science (Hacieminoglu, 2016; Montes, Ferreira & Rodriguez, 2018; Salta & Tzougraki, 2004). Likewise, attitudes may be defined as the cognitive and affective responses individuals have towards objects, events, or concepts within their surrounding environment (George, 2000). Attitudes may be seen as affective states characterised by preferences or aversions towards an item, someone, or occurrence, which serve to delineate an individual's disposition (Heng & Karpudewan, 2015). Furthermore, attitudes are seen as outcomes that may be obtained via the process of learning (George, 2000; Oh & Yager, 2004). As a consequence, the attitudes of students undergo changes, either via direct or indirect means, during the process of learning, influenced by the learning environment, including observation and experience, are crucial. Hence, the alteration in mind-set is predominantly shaped by educators and the setting within the classroom (George, 2000). Though behaviour cannot be observed directly, reports in the literature indicate that both negative and positive attitudes can affect the learning process (Ajzen & Fishbein, 2005). Therefore, the student's effort to demonstrate the expected learning outcomes in terms of teaching objectives, as a positive or negative attitude toward learning, is viewed as a predictor of the student's academic success (Hong-sheng, 2005; McAuley, Leskovec & Jurafsky, 2012; Osborne, Simon, & Collins, 2003; Tandogan & Orhan, 2007).

According to Lovelace and Brickman (2013), the cultivation of students' attitudes towards the field of chemistry holds substantial significance in the context of scientific education, since these attitudes exert a substantial influence on their academic achievements. According to Oh and Yager (2004), there is evidence to suggest that possessing favourable attitudes about science commitment can have a major bearing on an individual's lifetime learning and their level of interest in the field of science. Numerous scholars have conducted extensive inquiries into the importance of cultivating a favourable disposition towards the study of chemistry among students in secondary education. Their empirical investigations have consistently revealed a strong correlation between attitude and academic performance, as well as a predictive capacity for behavioural outcomes (Cheung, 2009; Khan & Ali, 2012; Meral, 2019; Salta & Tzougraki, 2004). Numerous studies in the literature have indicated that students who possess a good attitude exhibit higher levels of motivation towards attaining academic achievement, in comparison to their counterparts who possess a negative attitude (Adesoji, 2008; Brandiet, Xu, Bretz & Lewis, 2011; Heng & Karpukwan, 2015; Lerman, 2014). This supported by the research conducted by Mushinzimana et al. (2016); Ngila and Makewa (2014); and Weinburgh (1995), who found a correlation between students' academic success and their perspective on science subjects. According to Ozden's (2008) research, it is crucial to consider many aspects that might potentially disturb an optimal teaching and learning environment while designing instructional materials. If not identified and resolved, the presence of these disruptive factors could have a significant impact on the cognitive skills and active participation of learners in the teaching and learning process by influencing their attitudes, behaviours, and motivation. This points to the fact that when students develop a negative attitude toward mastering the subject of chemistry, it tends to derail the development of an in-depth understanding of basic organic chemistry concepts which creates challenges in learning the subject.

One of the effects of Science Education is to encourage the development of a favourable attitude toward science among a variety of individuals (Hacieminoglu, 2016). A variety of studies have indicated that students generally hold more favourable attitudes towards biology compared to chemistry (Awan & Sarwar, 2011; Cheung, 2009). Osborne, Simon, and Collins (2003) argue that the decrease in students' favourable views towards science and science-related professions might be ascribed to their insufficient understanding. The absence of pertinent material and pedagogical techniques at the school level has been identified as the cause of these aspects in several research and reports conducted in the US and Europe (Hofstein & Mamlok-Naaman, 2011). Furthermore, a number of studies have been conducted to investigate the attitudes of secondary school students towards the field of chemistry education. Research undertaken in Chile to elucidate the attitudes of secondary school students towards chemistry, are documented by Montes et al. (2018). Based on the findings, it can be observed that Chilean students exhibited a state of indifference towards the subject of chemistry. The individual has a generally favourable affective disposition towards the field of chemistry, but acknowledging the inherent difficulty associated with its subject matter. In a similar vein, the study conducted by Salta and Tzougraki (2004) focused on investigating the perspectives of secondary school students towards chemistry, specifically in relation to its perceived level of difficulty, level of interest, practical value, and overall relevance. Based on their research findings, it was observed that Greek students exhibited a state of indifference towards the subject matter. While individuals acknowledge the importance of chemistry in their daily lives, many fail to grasp the relevance of doing chemistry courses for their future endeavours. Furthermore, the research findings indicated that there was no significant difference in boys' and girls' perceptions on the amount of interest, utility, and relevance of chemistry. Kubiatko et al. (2017) did supplementary study in the Czech Republic to investigate the attitudes of secondary students towards chemistry. The researchers directed their attention towards investigating the students' perspectives on chemistry from a four-dimensional framework. This framework encompassed the popularity and difficulty of chemistry, the relevance of chemistry in their lives, the utilisation of chemical aids and laboratory experiments, and the perceived impact of chemistry on their future endeavours. The findings revealed that while students acknowledged the significance of chemistry, they did not establish a tangible link between chemistry and their future aspirations. Consequently, the individuals formed fairly positive opinions about the field of chemistry. Furthermore, a considerable body of research has been dedicated to investigating the effects of instructional strategies on the attitudes of secondary school students. This research includes studies conducted by Alrawili, Osman, and Almuntasheri, 2022; Baafi, 2020; Gambari and Yusuf, 2014; Khan and Ali, 2012; Kousa, Kavonius, and Aksela, 2018; Seitan, Ajlouni, Nayel, and Al-Shra'h, 2020; Singh and Chibuye, 2016; Yallıhep, Akcay, and Kapici, 2021. According to the findings of these studies, instructional strategies are positively related to students' learning attitudes. This suggests that when instructors adopt the appropriate instructional method, they can generate the required level of interest among students learning chemistry, thereby positively affecting their conceptual understanding of organic chemistry.

Sources of Conceptual Difficulties in Organic Chemistry

Chemists use multiple symbolic representations to communicate and express themselves at the macroscopic level. The concept of the molecular level is employed to elucidate the processes seen at the macroscopic level by considering the dynamics and interactions of particles, including molecules, atoms, and electrons (Johnstone, 2000; Talanquer, 2011; Treagust, Chittleborough & Mamalia, 2004). Consequently, the visual representation of organic chemistry has distinct challenges stemming from the diverse range of presentations employed. Organic chemistry employs a variety of representations at the molecular/microscopic level. In accordance with the findings of Fessenden and Fessenden (1990), organic compounds are commonly represented using five fundamental formulae, namely the structural formula, condensed structural formula, extended (or expanded) structural formula, skeletal structure, and the International Union of Pure and Applied Chemistry (IUPAC) name of the molecule. Chemistry is a visual science that relies heavily on symbolic language to convey ideas (Rice, 2016). Hence, in order to acquire comprehensive knowledge in the field of organic chemistry, students must possess the ability to seamlessly travel through various visual representations of organic molecules (Cheng & Gilbert, 2009; Keig & Rubba, 1993). Many chemistry difficulties, particularly in organic chemistry, stem from students' failure to visualise structures and processes at the microscopic (molecular) level (Sarabi & Gafoor, 2018). It is not surprising therefore to appreciate how learners encountering organic compound molecules for the first time would be in a state of confusion if the teacher uses the several styles of representation interchangeably and inconsistently. The diverse presentation of organic formulas, according to Johnstone (2006), can cause complications for students, because each kind of representation emphasises different aspects of the molecule (Taber, 2002). In a study by Johnstone (2006) the students were required to recollect and rewrite organic equations in a variety of formats. Condensed equations were found to be easier to remember than extended formulae. According to Anderson and Bodner (2008), it is recommended that instructors utilize extended structural formulations rather than condensed structures. The extended structural formulas can display the atoms, bonds, and non-bonding electrons which provide the learner more room in their working memory to conceptualise the representation of organic compounds. Most often the extended structural formulas of organic molecules are misconstrued as a flat two-dimensional molecule in the mind of a learner at the introductory level. The skeletal formulas are the most advanced and simplified version. As a result, they are rarely utilised at the introductory level, but they are ubiquitous in advanced organic chemistry courses. According to Bodner and Domin (2000), it takes time for line and bond structures to become true symbols for learners, because this needs formal comprehension at all three levels of Johnstone's triangle. It has been discovered that students' ability to solve chemical problems is typically tied to their ability to interpret the many chemical representations that are employed (Taber, 2002). A comprehensive understanding of structural representations of organic compounds is essential for the recognition of functional groups, identification of reaction types, and formulation of reaction processes. In contrast, a significant number of students encounter difficulties in comprehending structural representation, particularly in relation to line and bond formulas (Harrison & Treagust, 2000; Hassan et al., 2004). Similarly, Cooper, Groove, Underwood, and Klymkowsky (2010) reported in a study conducted amongst chemistry students at Colorado University that many students at all levels had difficulty in constructing correct organic structures. These difficulties were also apparent in the students' interviews conducted by Cooper et al. (2010) as many of the students' expressed frustrations at not being able to determine the correct attachment of atoms.

Moreover, it is vital for learners to possess the ability to identify and represent organic compounds utilizing the IUPAC nomenclature guidelines, alongside employing structural formulas to illustrate these compounds. In a cross-sectional survey conducted by Adu-Gyamfi, Ampiah, and Appiah (2012), a total of 245 Senior High chemistry students in the Kumasi metropolis, Ashanti region, Ghana was examined. The objective of the study was to assess the students' ability in generating structural formulas of organic compounds based on their corresponding IUPAC names, specifically focusing on alkanes, alkenes, alkanols, alkanoic acids, and alkyl alkanoate. The findings of the study indicated that the students encountered difficulties in accurately constructing the structural formulas of these organic compounds. If the IUPAC nomenclature system and structural representation are correctly grasped, the student should be able to recognise, name, and draw even novel organic compounds. How the compound is represented affects the student's ability to recognize functional groups, substituents, and the longest continuous chain (skeletal, condensed, or extended). In paper representations, structures of organic compounds are invariably depicted as two-dimensional, flat molecules. As a result, students' ability to identify the orientation of atoms in a compound, isomers, and predict how organic compounds will react becomes more challenging due to this misconception in compound visualization. The difficulty in identifying isomers of organic compounds is related to the complexities and ambiguities surrounding the representation of organic molecules (Rice, 2016). The difficulty in detecting isomers of compounds among students can be attributed to their limited ability to recognize substituents or carbon chains, as well as their inadequate understanding of the three-dimensional nature of organic molecules. Recognising isomers is a challenge for learners who lack a comprehensive grasp of the structural representations of organic compounds. Consequently, these learners tend to select compounds that share similar shapes, either branched or straight, as potential isomers (Schmidt, 1997; Taagepera & Noori, 2000). The researchers reported that learners frequently limit isomeric interactions to compounds belonging to the same family. This demonstrates the level of difficulty students at the introductory level in organic chemistry have in conceptualising isomerism due to challenges in organic compound representation. A study conducted by Eticha and Ochonogor (2015) to identify the sources of difficulty for chemistry students concluded that students have conceptual difficulties in isomerism. Similarly, Nartey and Hanson (2021) discovered in their study amongst senior high school students in Ghana that, chemistry students considered isomerism a difficult concept to understand. These findings are also supported by findings from literature of works done by other researchers (Akkuzu & Uyulgan, 2016; Belachew, 2020; Bryan, 2007; Kyado, Achor & Adah, 2021; Sendur, 2012; Taagepera & Noori, 2000).

Another area of difficulty for students is recognising functional groups as a technique for identifying organic compounds. Categorization and classification are higher-order cognitive processes that are systematic. It draws on existing knowledge to infer new information (Domin et al., 2008). According to Domin et al. (2008), two methods of classification that may be utilized in the field of organic chemistry are rule-based categorization and similarity-based categorization. The rule-based approach is characterized by its stringent nature, requiring a comprehensive grasp of procedures in order to arrive at a definitive affirmative or negative determination. In contrast, the similarity-based technique relies on the learners' subjective assessment of a common characteristic. When prompted to classify a given organic compound, the student is provided with a set of important attributes: a high number of carbon atoms, the presence of heteroatoms, the connectivity of the parent compound, the existence of multiple bonds between atoms, and various types of functional groups are among the seven characteristics outlined by Domin et al. (2008). This list sheds light on the difficult and time-consuming process of classification. It is difficult for the student to select the most prominent attribute for the given situation because there are so many attributes, each of which provides a probable proper categorization. The critical attribute by which learners categorise molecules varies as they advance through the organic chemistry course, according to Domin et al. (2008). The researchers Domin et al. (2008) and Hassan et al. (2004) found that both higher-ability and lower-ability learners considered functionality to be the most important feature. Stereochemistry was the second most regularly utilised attribute by higher ability learners, while structural similarities were the second most commonly used attribute by lower ability learners. Some students struggle with categorization based on functionality. According to a study conducted by Strickland et al. (2010), a significant number of students enrolled in organic chemistry courses shown a lack of understanding when it came to explaining or defining the concept of a functional group. To an inept observer, organic molecules may look indistinguishable, as they typically consist of carbon, hydrogen, and oxygen atoms in various configurations. The chemistry syllabus for senior high school (SHS) students in Ghana and at the beginning level often encompasses many prevalent functional groups, including alcohols (-OH), carboxylic acids (-COOH), esters (RCOOR'), as well as aliphatic and aromatic hydrocarbons. Because each derived hydrocarbons contains oxygen, carbon, and hydrogen atoms, distinguishing between these families of organic molecules can be challenging (Hassan et al., 2004). Akkuzu and Uyulgan (2016) conducted a study which revealed that students exhibit significant misconceptions and possess limited comprehension in relation to various functional group-related concepts, including physical properties, acidity and basicity, intermolecular bonds, isomerism, aromaticity and aliphaticity, as well as reduction and oxidation. A comprehensive comprehension of structures and the ability to extract pertinent information from various representations of structures are essential prerequisites for accurately identifying organic compounds among students.

Myriad students struggle to understand that the many chemical reactions they learn in organic chemistry are confined to a few types. Most learners are required to create reaction-type mental slots into which reactions can be assimilated (Taber, 2002). Because students are at the introductory level, they do not have adequate previous knowledge of organic reactions which culminates in their difficulty in classifying organic reactions. Many students are perplexed by reactions that appear identical on the surface, reaction names that sound similar, and a lack of distinction between a nucleophile and a base (Ferguson & Bodner. 2008). Misconceptions and challenges from learners' earlier experience with general chemistry, contribute to further difficulties when trying to comprehend organic chemistry reactions. Other researchers have opined those organic reactions are difficult for learners at the introductory level because of misconceptions about compound reactivity and product stability due to bonding and electron density, among other factors (Rushton et al., 2008; Taber, 2002; Zoller, 1990). Organic reactions necessitate a high level of cognitive capacity (Taber, 2002). As a result, learners must be able to successfully relate the macroscopic (laboratory-based) reaction to the microscopic (molecular level) reaction to be able to depict the reaction using the appropriate reaction equation (symbolic). The challenges as reported in students' comprehension of organic reactions (synthesis) are also confirmed in several works (Ferguson & Bodner, 2008; Salame, Casino &

Hodges, 2020). Salame, Casino, and Hodges (2020) reported that science students consider organic reactions as difficult concept because of their over-reliance on memorisation of a large number of reactions, reagents, and rules. Further, for students at the introductory level of chemistry, the principles governing organic synthetic reactions pose a unique challenge. According to Schaller, Graham, and Jones (2014), the majority of students consider this section of organic chemistry to be difficult because they do not comprehend the significance of the synthesis of organic compounds. It has been indicated that the sequence involving organic synthesis or preparation provides possibly the most complex challenges in the study of organic chemistry (Teixeira & Holman, 2008). All the reagents and conditions needed to convert one organic chemical into another must be listed in detail by the student in order to solve a preparation problem in organic chemistry (Carney, 2015). Knowing the structure of organic molecules and how they react to different chemical reagents is essential, but so is knowing how these changes take place (that is, mechanism). It is difficult for students to solve synthesis problems because they have to select the correct reactions from the vast number of preparation methods they have learned and apply them in the correct order to make the desired compound (Rose, Pennigton, Behmke, Kerven, Lutz & Paredes, 2019).

Understanding the correlation between the molecular structure of a substance and its physical and chemical characteristics is a fundamental concept in the field of chemistry. This knowledge is crucial for grasping subjects like organic chemistry (Rice, 2016). The underlying principle that the spatial configuration of atoms in a material has a direct impact on the observable macroscopic properties and chemical behaviour of said substance is of utmost importance and can serve as a foundational concept for students to grasp many physical and chemical processes. Students who lack a comprehensive understanding of the fundamental principles that establish the connection between structure and property are compelled to depend on rote memory (Cooper et al., 2010). The perception of organic chemistry as a topic that relies heavily on memory might be attributed to the inability of students to utilize structural information in order to deduce the mechanisms and rationales behind molecular interactions (Rice, 2016). Multiple studies have been conducted to demonstrate the challenges faced by students in understanding the physical and chemical characteristics of organic molecules (Othmann et al., 2008: Schmidt, 1997; Smith & Nakhleh, 2011; Taagepera & Noori, 2000).

Instructional Design

The instructional process entails the systematic development of instructional design strategies. According to Merrill (2002), the implementation of instructional design that is effective has the ability to activate the proper cognitive processes in the learner, hence leading to more successful learning outcomes. Instructional Design (ID) refers to a systematic approach employed to consistently and reliably create educational curriculum. This process involves a creative, active, and iterative methodology (Branch & Merrill, 2011; Gustafson & Branch, 2002). According to Smith and Boling (2009), ID is a systematic process that is represented by models that are based on theory and grounded in data with a focus on problem-solving (Tracey & Boling, 2013). Also, ID is considered a method of presenting lessons, courses, and learning activities contained within a unit of learning (Koper, 2006). In other words, instructional design is a process by which an instructor makes use of a readily available resource to satisfy a learner's demand for knowledge transfer. Işman (2011) subsequently defined instructional design as a systematic approach to conceptualizing, developing, and implementing instructions. This strategy facilitates the creation of instructional materials by instructors, using a methodical approach to designing instruction that encompasses many stages, including instructional analysis and assessment (Smith & Ragan, 2005). Thus, ID can be defined as a systematic and reflective process for transforming learning and instruction principles into plans for instructional materials, activities, information resources, and evaluation that ensure the quality of instruction (Smith & Ragan, 2005). As such, ID provides a framework for developing instructions based on the requirements of a teaching and learning environment. Instructional design will be defined in this study as the utilization of instructional and learning theories to develop a theory-based lesson plan and structured learning environment to significantly improve the teaching and learning of organic chemistry.

Instructional design is intended to be an iterative process that involves goal setting, selection of teaching and learning strategy, technology selection, identification of educational media, and performance assessment (Gustafson & Branch, 2002). ID places a premium on human learning by purposefully arranging sets of external events within the teaching and learning contexts (Gagné, Wager, Golas, & Keller, 2005). According to the authors the process for instructional design is most effective when it is matched to a relevant context. However, educational contexts are frequently complex, with numerous issues surrounding teaching and learning (Alshumaimeri, 2022; Gu & Johansson, 2013). Consequently, it is imperative for instructional design models to exhibit sensitivity towards diverse educational settings and possess adaptability to address intricate teaching and learning scenarios. Instructions can be formulated in several manners, contingent upon the requirements and circumstances, in order to align with the structure of a certain framework. The instructional design used to instruct secondary school students in organic chemistry will likely vary from the model used to instruct adults in the workplace. Instructional design models, as defined by Smith and Ragan (2005), are visual representations of the instructional design process that emphasise essential features and linkages and serve as a guide for organising and structuring the process of developing new pedagogical materials. According to Gagne, Briggs, and Wager (1992, pp. 4-6), the following five assumptions should guide the planning and design of an instruction in aiding the learning of the individual, systematically planned education may have a significant impact on human development, both in the short and long term, and it should be founded on research into how people learn best.

Gustafson and Branch (2002) divided ID models into three categories: product-based, system-based, and classroom-based. Product-oriented instructional design methods aim to develop a curriculum for use in independent study or online courses (Gustafson & Branch, 2002). An example of a product-oriented identification model is Tony Bate's activity model. It is possible to think of the system-oriented instructional design approaches as a more comprehensive version of the classroom-oriented paradigm (Gustafson & Branch, 2002). The approach accounts for the extensive time and money needed to create a full programme of study (Botturi, 2003). They may be implemented in many business situations and put the organization's mission first when designing training. Finally, classroom-based instructional design models are seen as potential models for designing learning instructions by classroom teachers, who often work alone as both the designer and deliverer of an instruction (Gustafson & Branch, 2002). These models serve as a road map or guide for improving teaching and learning experiences in the classroom. Models like ASSURE, Kemp, and the Gagne nine event of instructions fall into this group. It has been thought that the classroom, the teacher, and the students are all parts of the classroom-oriented education process that might use some fine-tuning (Hamdani, Gharbaghi, & Sharifuddin, 2011). On the other hand, product-oriented models place a premium on the learning process in order to provide effective outputs. Systems-oriented models are developed with the intention of presenting a comprehensive pedagogical framework for arranging educational tasks and prerequisites (Basu, 2018).

Generally, the classroom learning environment is predominantly based on the traditional method of teaching and learning where the teacher act as the ultimate narrator and custodian of knowledge in the class for providing every information and explaining concepts to students whilst the students act as passive listeners and receptors of information (Hillman & Eibenschutz, 2018). Students are instructed in a manner conducive to sitting and listening in the majority of traditional teaching and learning methods (Tularam & Machisella, 2018). Also, the traditional mode of instruction is the chalk and talk method where the teacher speaks to the entire class with very minimal opportunity for students' interactions with the teacher (Stehlik, 2018). It is often argued that these approaches may not provide students with valuable learning skills and the development of deep and meaningful learning (Tularam & Machisella, 2018). The teaching method in question has been found to have limited effectiveness in capturing students' attention (Schwerdt & Wuppermann, 2011). Research suggests that when students are not actively engaged in classroom activities, they may become disoriented and lack motivation to participate in lessons using this pedagogical approach (Bergdahl, Nouri, Fors & Knutsson, 2020). Instructional planning is the deliberate and distinct arrangement of various tasks and activities designed to engage students in the learning environment. It essentially provides a systematic approach to lesson development by establishing a series of activities and steps toward authentic assessment of instructional strategies and learning processes (John, 2006; Cruickshank, Jenkins & Metcalf, 2006; Panasuk & Todd, 2005). The absence of an effective instructional plan results in aimless wandering in the classroom, non-academic discussion, inconsistencies between previous and current lessons, and a lack of effective and lifelong learning (Iqbal, Siddiqie & Mazid, 2021). The authors argue that the majority of teachers provide explicit guidance to students on which materials to read and which to omit in order to optimise performance on examinations. Consequently, students tend to depend on rote memory as a means to achieve success in examinations, while educators predominantly evaluate students' progress through the employment of summative assessment methods. In the pursuit of enhancing the quality of education, it is crucial to promote profound and significant learning through the implementation of student-centred instructional design strategies in the classroom. This approach should be grounded in fundamental theories and principles of instructional design, learning, and assessment, with the aim of eliciting the desired learning outcomes. Classroom instructions that are executed and designed to reflect theory-based lesson plans have the potential to:

i. Provide students with the structure and direction necessary to receive an engaging and relevant education.

ii. Allow instructors to differentiate instruction and increase student choice to meet the diverse learning needs of our students.

iii. Integrate modern technologies and improved resources into students' daily lives, increasing lesson interactivity and creating a richer learning environment.

iv. Allow for the mapping of learning objectives and the assessment of their achievement.

v. Maintain relevance in lessons to increase engagement and comprehension and foster greater independence and mastery of a subject (Kotecha, 2021).

Efforts have been made to blend diverse teaching and learning approaches suited to the educational contexts to improve teaching and learning (Nagpal & Kumar, 2020). For instance, the generic "ADDIE model" from 1975 has had a significant impact on the advancement of following models such as the" Dick and Carey Model" from 1978, the Future UID Model from 2000, and the Kemp Model from 2004. According to Nagpal and Kumar (2020), researchers have modified and adapted the ADDIE model that has been developed to address the changing requirements of learners and the many environments in which learning takes place. According to the researchers, the integration of technology into generic ADDIE resulted in the creation of new models such as “ASSURE Model (1999),” the “Successive Approximation Model 2011,” and “TPACK-IDDIRR” (Angeli & Valanides, 2005; Jang & Chen, 2010). Instructional designs rooted in behaviourist principles and constructivist epistemologies, exemplified by the utilisation of the 5E Model, have had significant influence over instructional practises across many educational institutions. Through the incorporation of ICT into constructivism, new models such as TPACK (Mishra & Koehler, 2006), ICT-PACK (Angeli & Valanides, 2009), RCET (Swan, 2005), and ADAPT (Tuckman, 2002) were developed with the advent of ICT. The emphasis shifted towards the creation of integrated models like the ARCS Model (Keller, 1984), the Situational Instructional Design Model (Zemke, 2002), and the Ishman-2011 Model to mix various pedagogical techniques and learning theories with technology. Blended instructional designs like the ASSURE Model, ADAPT, and ICT-PACK were developed as a result of the integration strategy in ID creation. ID development in instructional designing systems still heavily relies on sociocultural theory, Gagne's instructional events, and Merrill's principles of instruction (Kumar & Nagpal, 2022).

Making abstract concepts accessible and engaging for students, as well as making and justifying instructional decisions that lead to their mastery of the material (Abocejo & Padua, 2010; Coe, Aloisi, Higgins & Major, 2014; Rodriguez & Abocejo, 2018), are all essential components of high-quality education. Instructional strategies with a theoretical foundation have been shown to improve classroom instruction and student learning (Crawford & Jenkins, 2018; Kristanto, 2017; Xu & Shi, 2018), so there is good reason to prioritise them. There is an increasing tendency towards the use of numerous instructional and learning theories in the creation of blended learning (Campbell, Craig & Collier-Reed, 2020; Chou, 2020), hence it is important that instructional plans be based on theory (Iqbal, Akhter & Mazid, 2021). It is crucial to develop a blended instructional plan that incorporates several instructional and learning theories in order to produce an educational plan based on theoretical frameworks and promote an ideal teaching and learning environment (Iqbal, Akhter & Mazid, 2021). Blended learning is defined as the integration of digital tools with traditional classroom settings (Graham, 2006). For his part, Cronjé (2020) suggests redefining blended learning as "the appropriate use of a combination of teaching and learning theories, methods, and technology to optimise learning within a given context" (p. 120). Blended learning has been defined by other academics as the use of many approaches to teaching and learning (Driscoll, 2002; Rossett, 2002). In this research, "blended learning" is defined as the use of many pedagogical tenets to create an evidence-based strategy for teaching organic chemistry. The following are some of the functions that instructional design models may fulfil, as determined by an analysis of 40 models by Andrews and Goodson (1980, p.164):

“

i. Improving learning and instruction by following a systematic approach
ii. Improving management of instructional design and development procedures by monitoring and controlling the functions of the systematic approach
iii. Improving evaluation processes (including learner performance)

iv. Testing or building learning or instructional theory by means of theory-based design within a systematic instructional model."

In their research, Kumar and Nagpal (2022) examined the impact of the constructivist blended instructional paradigm on the performance of 37 B.Ed. student teachers, 27 cooperative principals, and 796 students in grades 6 through 10 at 18 Indian senior secondary schools. The study's findings showed that the Constructivist Blended Instructional Paradigm significantly affects the efficacy of future teachers' classroom performance. Hunt, Touzel, and Wiseman (2009) argue that good instructors help their students develop skills including critical thinking, teamwork, problem solving, and active participation. Also, Hafiz et al. (2021) in their study assessed the effectiveness of a theory-based lesson plan in the teaching of microeconomics in Bangladesh amongst 151 university undergraduate students. The researchers have shown that the utilization of a theory-based lesson plan is crucial and impactful in the development and execution of instructional strategies within the educational setting, with the aim of enhancing students' comprehension of conceptual knowledge. Further, it has been intimated that the effective blending of fundamental instructional design and learning theories is critical for developing instructional activities that take into consideration students' learning needs in creating a conducive learning environment to produce desired learning outcomes (Morkie, Dornan & Eika, 2013). From the literature, it appears that very little has been done to improve the teaching and learning of organic chemistry amongst SHS science students in Ghana through the development and implementation of a theory-based lesson plan. In this study a Theory-Based Organic Chemistry Instructional Plan (TB-OCIP) will be developed to improve the teaching and learning of organic chemistry amongst SHS science students in Ghana.

Theoretical Design Framework

The model for developing the theory-based organic chemistry instructional plan (TB-OCIP) as an educational tool for improving the teaching and learning of organic chemistry was adapted from the theory-based instructional plan and constructivist blended design models developed respectively by (Iqbal, Akhter & Mazid, 2021) and (Nagpal & Kumar, 2020), taking into account both teachers' and students' preferred methods of instruction that was determined in Phase 1 of the study. This study's primary methodology, Design-Based Research (DBR), guides the development of the instructional design in a manner consistent with its primary objective. Because of this, DBR is seen as a cutting-edge theoretical field of knowledge (Alghamdi & Li, 2013; Bakker & van Eerde, 2015; Dede, 2005; Hoadley, 2004) based on flexible and robust design models generated from empirical research. These real-world settings are utilized to advance the study's theoretical considerations (McKenney & Reeves, 2013).

Reigeluth and Carr-Chellman (2009) defined instructional theory as the identification of methods that provide the optimal conditions for achieving a learning objective. Moreover, they stated that in order for an instructional model to be effective, it must be compatible with other learning theories, thereby establishing connections between what is learned and the conditions under which it occurs. According to Driscoll (2000), instruction is a well-planned arrangement of learning conditions meant to facilitate the attainment of learning objectives. Also, Gagne (1985) opines that instruction consists of a series of external events intended to facilitate the internal processes of learning. Therefore, the purpose of instructional theory is to be prescriptive in order to provide teachers and instructional designers with guidelines for ensuring student learning. Reigeluth and Carr-Chellman (2009) suggested that "for an instructional theory to be effective, the following four components should be taken into account when designing instruction: the learner, the learning activity, the educational environment (learning conditions and instructional method), and the reference frame (the context in which learning occurs)" (p. 345).

In this study, the instructional design constitutes the blending of Gagne's instructional theory (lesson sequence), situated and video-based learning approach (learning environment), and formative assessment (assessment technique). The purpose of combining these theoretical approaches is to generate a Theory-based Organic Chemistry Instructional Plan (TB-OCIP) to improve the teaching and learning of organic chemistry and how it works in practice amongst SHS science students in Ghana.

Gagne Nine Event of Instruction: According to a 2000 study by Smith and Ragan, Gagne's model is "one of the most well-known and widely used instructional models in the field of instructional design." Reigeluth (1999) argues that Gagne's methodology is a prescriptive approach to education. Reigeluth implies that this helps educators assess their student's academic strengths and weaknesses so they may better serve those who need it Smith and Ragan (2005) argue that Gagne's "nine events of learning" was the first conceptual framework for instructional design. A study of American instructional designers (Christensen & Osguthorpe, 2004) found that Gagne's instructional events were the most popular model. Researchers have used this framework to study many different fields, including ethnic educational context (Garcia & Denton, 1980), adult learners (Bonner, 1982), e-learning (Hashim, 1999), health education (Kinzie, 2005), and teacher education (Krull et al., 2010, 2007; Zhu & Amant, 2010).

According to Gagne (as cited in Gagne, Wager, Golas & Keller, 2005, p.7), "instruction must take into account the entire set of external factors, such as environment, resources, and management of learning activities, which interact with internal conditions, such as the state of mind the learner brings to the learning task, previously acquired skills, and personal goals of the individual learner." The internal aspects identified by Gagne that have not been taken into account by other instructional designers are potentially game-changing. Learning, as described by Gagne (1977, p. 3), is "a change in human disposition or capability that persists over time," and this transformation is reflected in how a person acts. Internal learning stages impacted by external events are described by Geremias, Lopes, and Soares (2020). What this means is that internal circumstances like previously learned skills interact with external elements like the classroom setting, teaching/learning activities, and course materials (Gagne, et. al, 2005). Various learning outcomes develop as a result of the interaction between external variables and internal situations. The intellectual skills, cognitive strategy, linguistic information, physical abilities, and attitudes as learned skills are the five main categories into which Gagne divides these learning outcomes (Gagne et al., 2005). Teaching is effective if it helps students with the mental processes involved in taking in and analysing data (Gagne et al., 2005). Gagne determined the optimal order of educational activities that match to the stages of learning (Gündodu, 2016; Senemolu, 2002). Instructional experiences outside the classroom may have an impact on these procedures (Gagne et al., 1992). Gagne (1974) proposes a nine-step method that may be used to construct a framework for learning that takes into account both the learner's internal and external factors:

"

1. Gaining attention
2. Outlining learning objectives
3. Recall of previous knowledge
4. Presentation of content
5. Providing learning guidance
6. Eliciting performance
7. Providing feedback
8. Assessing performance
9. Enhancing retention and transfer"

According to Driscoll (2000), the events that occur are situated outside of the learner and are designed to support and enhance the internal process of learning for individuals. Gagne' (1985) provides a comprehensive analysis of the relationship between his nine events of teaching and the various stages of internal learning processes. This analysis suggests that these events might be utilised as a structured framework for making informed decisions regarding instructional strategies (Denton et al., 1980). According to Gagne, these nine events possess the potential for applicability in many teaching and learning activities, irrespective of their specific application or sequence. The use of these events may be altered depending on several factors such as the desired outcomes, the instructor's preferences, the students' characteristics, and the instructional resources available. "The events apply to the learning of all types of learning outcomes, thus the order of these events within a lesson or lesson sequence is approximative and may vary slightly based on the learning objective" (Gagne & Brigges, 1974, p. 135). The nine events of learning identified by Gagne play a significant role in developing a lesson plan for an instructional activity. A number of teachers worldwide have adeptly incorporated Gagne's nine stages of learning into their instructional strategies, with positive outcomes (Tambi, Bayoumi, Lansberg & Banerjee, 2018). The Gagne nine events of learning combine external instructions with the learner's intrinsic cognitive learning process and retention, perfectly reflecting the learner's individuality, readiness, and motivation to learn (Mei, Ramli & Al Hertani, 2015).

Situated learning: Situated learning was initially established by Brown, Collins, and Duguid (1989), and later refined by Lave and Wenger (1991). It has since had a huge effect on the way we think about education. Elements of the idea of situated learning (Brown, Collins & Duguid, 1989; Lave & Wenger, 1991; Motteram, 2013) are starting to gain traction as a viable means of revitalising our knowledge of, and recommendations for improving, the process of knowledge creation and organisation. Knowledge should be provided in a real-world context, as advocated by the contextual learning theory. Students are better able to demonstrate their understanding of course material when applied in a real-world setting. "Authentic context" (Lave & Wenger, 1991, p. 41) "explores how classroom concepts relate to one another and places that knowledge in real-world contexts for participants to investigate directly." Students can show what they know or how well they understand what they have learned in these settings (Hammersley, Levine, Cornwell, Kusnick & Hausback, 2012; Herrera & Riggs, 2013; Streule & Craig, 2016; Waldron, Locock & Pujadas-Botey, 2016). Newcomers should start out in real-world situations where they can put their skills and expertise to work and benefit from tangible artefacts. As a rule, this calls for communication and cooperation among members of a certain "community of practise." They start out as part of this group, but they leave when they take on more demanding tasks and become experts in their field. 'Legitimate Peripheral Participation' (Lave & Wenger, 1991) describes this typically inadvertent phenomenon. Legitimate periphery is foundational to the contextual learning and communities of practise framework proposed by Lave and Wenger (1991).

Learning, according to Lave and Wenger (1991), occurs when people take part in and become a part of the communities in which they are acculturated. In addition, Lave and Wenger (1991) claimed that knowledge is competence in the complex network of interactions between people and things. According to Lave and Wenger (1991), students develop their identities through a dialectical process of social involvement and active learning in this setting. Instead of seeing learning as a process by which an individual acquires facts from a disembodied body of knowledge, Lave and Wenger (1991) argued that it is a social and cultural phenomenon. In other words, as opposed to the solitary act of learning, it is a process of collective engagement in real-world contexts. People acquire knowledge and skills by participating in dynamic individual processes within a given community, rather than as "intellectual concepts produced by reflection" or "inner energies produced by psychic conflicts," as Fenwick (2001) puts it. To put it differently, "knowledge is not a substance to be ingested and then transferred to a new situation”; in contrast, "knowledge is an integral part of the process of participating in the current situation" (p.34). According to the situational learning theory, learning occurs and is mediated through interactions with members of the community or within a "community of practise." Members of a community of practise exchange and refine practises, learn from one another, and advance their own personal, professional, and intellectual growth as a result of participating in the community (Lave & Wenger, 1991; Mills, 2013).

Formative assessment: According to the literature (Bennett, 2011; Van der Kleij, Vermeulen, Schildkamp & Eggen, 2015), formative assessment is most effective when it has a direct bearing on students' learning processes and improves their learning outcomes. Because of its great potential to improve students' education, formative assessment has been recognised as a policy pillar in the field of education (Black & Wiliam, 1998). Different conceptualizations of formative assessment can be attributed to the fact that different theoretical perspectives place emphasis on different aspects of the process (Baird et al., 2014; Briggs et al., 2012; Van der Kleij et al., 2015). What ties these ideas together at their core is an emphasis on collecting evidence of student learning and acting on that evidence to improve instruction. As a result, feedback is widely acknowledged as an important component of formative assessment (Bennett, 2011; Stobart, 2008). According to Hattie and Timperley (2007), feedback is any comments made by a teacher or student about a student's performance or knowledge. Evans (2009) argues that all interactions resulting from assessment design, both inside and outside of the naturalistic learning environment, can be considered feedback. Teachers can better meet the needs of their students by adjusting their lessons and commenting on their progress based on the results of various forms of assessment. In addition, with this type of information, students can take charge of their own education (Bennett, 2011; Black & Wiliam, 1998). Strategies for formative assessment include Assessment for Learning (AfL) and Data-Based Decision Making (DBDM) (Van der Kleij et al., 2015). Data-based decision making (DBDM) is the practise of using data to accomplish goals such as enhancing pedagogy and student learning (Wayman, Spikes & Volonnino, 2013). Schildkamp and Kuiper (2010) explain the term "data-based decision making" (DBDM) as the systematic investigation of data sources within a classroom with the intention of applying the gained insights to improve the quality of instruction and learning. The accountability principle drives the implementation of Data-Based Decision Making (DBDM) in the classroom. The onus is on teachers to use data to make educated decisions about their classroom practises (Ledoux, Blok, Boogaard, Kruger, 2009; Wayman, Jimerson & Cho, 2012). Data-based decision making (DBDM) in education has been shown to have positive effects on student learning (Carlson, Borman, & Robinson, 2011; Lai, Wilson, McNaughton, & Hsiao, 2014; Poortman & Schildkamp, 2016; van Geel, Keuning, Visscher & Fox, 2016). Both qualitative methods, such as structured classroom observations, and quantitative methods, such as periodic assessment results, are employed in the data collection process for DBDM (Wayman, Cho, Jimerson & Spikes, 2012).

The use of assessment data as a significant resource in data-based decision making (DBDM) is a popular strategy for determining efficient means of enhancing educational outcomes. Exemplifying this category of information are homework assignments and systematic classroom observations (Ikemoto & Marsh, 2007) that students are expected to complete outside of class time. Increasing students' conceptual understanding is just one example of the kinds of goals that can guide the DBDM approach. These data need to be analysed and interpreted in order to determine what steps, such as changes to the curriculum, can be taken to improve organic chemistry education for science majors. Changing the teacher's role significantly in the classroom is a necessary part of implementing formative assessment, which is why its importance should not be minimised. There should also be a shift in the balance of power in the classroom, with both teachers and students bearing some of the weight for the success or failure of a course or programme (Black & William, 1998).

The primary emphasis of Assessment for Learning (AfL) is placed on evaluating the calibre of the learning process rather than only on its end results (Stobart, 2008). This phenomenon can also manifest itself within the confines of the classroom and among individual students within the school. According to Klenowski (2009), Assessment for Learning (AfL) can be thought of as a routine activity in which students, teachers, and peers engage in talk, demonstration, and observation to learn, reflect, and act in ways that further learning. Observations, portfolios, practical demonstrations, paper-and-pencil tests, peer assessment, self-assessment, and dialogues are all examples of assessment sources that can provide the information referred to in this definition (Gipps, 1994). This information provides continuous feedback to direct the learning process. Focus is placed on active participation in class discussions as part of a learning process that includes inquiry, self-reflection, and analysis (Hargreaves, 2005). Assessment for Learning (AfL) relies on teachers' abilities to accurately interpret data about their students' learning, make inferences about their development, and use these findings to inform their teaching and student feedback (Bennett, 2011). The effective implementation of Assessment for Learning (AfL) has been found to be associated with enhanced student learning and academic performance (Anderson & Palm, 2017; Fletcher & shaw, 2012; Pinger, Rakoczy, Besser & Klieme, 2018; Yin, Tomita & Shavelson, 2013). Continuous interaction between students and teachers to meet students' specific needs is central to Assessment for Learning (AfL). Continuous conversations and feedback cycles, in which immediate feedback is used to direct future learning endeavours, characterise Assessment for Learning (AfL) in the classroom (Stobart, 2008). Assessment is a crucial part of the learning process and should be integrated into it without disrupting the flow. Students' active participation in self- and peer-assessment activities demonstrates the importance of their involvement in Assessment for Learning (AfL). These methods have been shown to improve students' understanding of the material and their motivation to learn (Elwood & Klenowski, 2002). The quality of the learning process is emphasised in AfL rather than the outcomes (Stobart, 2008). This is something that students may experience in the classroom. Klenowski (2009) describes AfL as a "part of daily practise by students, teachers, and peers that seeks, reflects on, and responds to information through dialogue, demonstration, and observation in ways that increase continuing learning" (p. 9). Participation and discussion in class are emphasised as essential components of learning and reviewing material (Hargreaves, 2005). The success of AfL hinges on teachers' abilities to gather relevant data on their students' progress, make inferences based on that data, and use those inferences to inform their teaching and provide them with constructive feedback (Bennett, 2011). According to multiple studies (Andersson & Palm, 2017; Fletcher & Shaw, 2012; Pinger, Rakoczy, Besser & Klieme, 2018; Yin, Tomita & Shavelson, 2013), AfL has a positive impact on students' academic performance when implemented correctly. A key feature of AfL is the ongoing dialogue between students and instructors to meet the needs of the students. Assessment for Learning (AfL) occurs frequently in the classroom, taking the form of ongoing conversations and feedback loops. These exchanges necessitate the use of real-time feedback to guide future efforts at education (Stobart, 2008). Therefore, assessing progress is essential throughout the learning process. Assessment for Learning (AfL) relies heavily on student input during the implementation phase. Students can contribute to AfL by, for example, evaluating their own performance and that of their peers. These methods are proven to improve students' knowledge of the subject matter and their motivation to learn (Elwood & Klenowski, 2002).

Video-based learning: According to Hamill (2012), technology has become an essential element of the educational process. Widespread adoption of digital learning environments has facilitated the incorporation of a variety of video materials into the instructional setting (Poquet, Lim, Mirriahi & Dawson, 2018). The utilization of e-learning applications has witnessed a surge among educators and learners due to advancements in technology (Kolekar et al., 2018). Consequently, these applications have been helpful in bringing about noteworthy transformations in the learning experiences of students (Sloan & Lewis, 2014). Video-based learning (VBL) is a method of acquiring knowledge or skills using instructional videos. The incorporation of both audio and visual stimuli is a salient characteristic of the video. According to Majumdar (2017), visual features play a central role in conveying information, with audio serving as a supplementary component. The VBL technique has unique attributes that render it a proficient educational strategy capable of supplementing and partially substituting traditional methodologies. The methodology described by Yousef et al. (2014) is a robust model utilized to augment both student happiness and learning results. In general, conventional instructional practices adhere to a sequential progression through textbook chapters, resulting in student resistance to learning, a tendency towards passivity in the learning process, insufficient cultivation of critical thinking skills, limited comprehension of acquired knowledge, and a diminished likelihood of practical application in daily life (Chen, 2012). According to Guseva and Kauppinen (2018), the utilization of educational films has the potential to support the shift from traditional teacher-centred classrooms to learner-centred environments. Furthermore, the research conducted by Masats and Dooly (2011) provides evidence that the use of video in educational settings brings forth novel and imaginative pedagogical viewpoints. According to Santagata and Guarino (2011), the utilization of videos in educational settings allows teachers to actively observe students as they engage in problem-solving activities, articulate their cognitive processes, and communicate their problem-solving strategies. Simultaneously, teachers play a crucial role in fostering and enhancing students' ideas, while also facilitating explicit connections between different visual representations and the interrelationships among concepts and procedures. The key attribute of the informative video snippets is in the extent and calibre of information and knowledge conveyed, hence fostering learners' motivation and engagement in active learning (Giannakos et al., 2016).

In their examination of existing scholarly literature, Gaudin and Chaliès (2015) identified video watching as a distinct and efficacious instructional instrument. Furthermore, the utilization of videos serves as a means to enhance students' acquisition of skills and processes within the educational context (Otrel-Cass et al., 2012). According to DeLozier and Rhodes (2017), educational videos have the ability to provide students with the necessary skills to acquire new knowledge, while simultaneously enhancing their ability to facilitate peer-to-peer contact. According to Giannakos et al. (2016), the use of films in educational settings enables students to surpass the practical constraints of the physical world and delve into the extensive opportunities presented by digital environments. According to Fern et al. (2011), the utilization of videos as a virtual learning medium has proven to be very successful in capturing and disseminating knowledge. Additionally, videos create a dynamic learning environment that enhances students' ability to absorb and remember information more efficiently. The flipped classroom is a pedagogical approach that centres on the notion of students engaging with instructional films before going to class, followed by activities such as exercises, problem-solving, and collaborative interactions with both peers and the instructor. This approach is considered to be among the student-centred teaching methodologies. In contrast to the usual technique, this strategy not only facilitates increased student motivation (Wang, 2016), but also enhances student accomplishment (Akcayr & Akcayr, 2018). Furthermore, Akcayr and Akcayr (2018) draw the conclusion, via a comprehensive examination of existing research, that this particular model effectively enhances the learning process and promotes student achievement. Additionally, it fosters increased enthusiasm to study and cultivates good student attitudes. Sabli, Mirosavljevi, and Kugor (2020) assert that video has emerged as a highly efficacious medium for learning, facilitating the acquisition and dissemination of knowledge. Moreover, it offers a dynamic learning environment that enhances students' comprehension and retention of information. Furthermore, the researchers propose that the utilization of Video-Based Learning fosters enhanced engagement among stakeholders involved in the educational process. This approach also contributes to heightened levels of student satisfaction, attentiveness, and motivation, thus resulting in increased classroom involvement.

These theories are intimately interlaced and act as a guide for developing an effective lesson plan in any subject such as organic chemistry (Ghanizadeh, Hoorie & Jahedizadeh, 2020; Green & Tolman, 2019). According to Sousa (2016), the creation of a lesson delivery plan based on the synthesis of these instructional and learning theories has the potential to empower learners to be active participants in class, attentive and retain information, self-motivated, and develop in-depth learning (conceptual understanding).

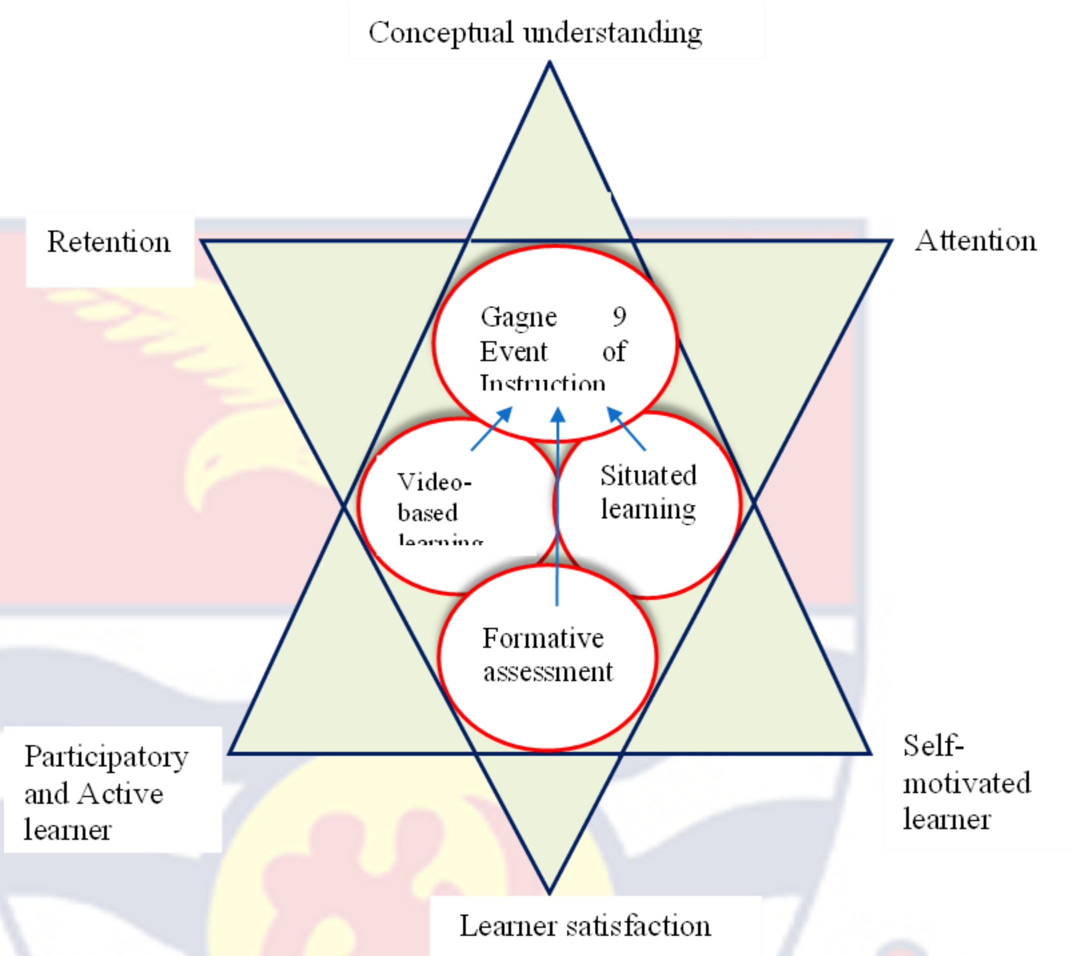


Figure 1: Theoretical design framework of the TB-OCIP (Gyang, 2023)

Design-Based Research

In educational research, an intricate and robust correlation exists between theory and practise, as posited by Moore (1982). Pring (2004) underscored the significance of educational research in advancing theoretical frameworks and then implementing them in practical settings. According to Neuman (2007), theory may be described as a "compilation of interconnected abstractions or concepts that serve to consolidate and structure our understanding of the social realm" (p. 24). In contemporary educational research literature, there is a growing consensus that educational research often lacks a connection to educational challenges and the practical realities of everyday teaching practises (Juuti & Lavonen, 2006; Sari & Lim, 2012). Indeed, several hypotheses have been put forth to elucidate this phenomenon. One possible explanation is that a significant portion of educational research places emphasis on "research about education" (Juuti & Lavonen, 2006, p. 54), which aims to comprehend educational issues. Conversely, there is a lesser focus on "research for education" (Juuti & Lavonen, 2006, p. 54), which aims to connect the theoretical and practical aspects of research within the educational setting (Henn, Weinstein & Foard, 2006).

In light of the limitations of certain conventional research methodologies in bridging the gap between theory and practise in educational research, the field of design-based research has emerged as a viable approach for generating practical knowledge to inform educational practise (DBRC, 2003; Dix, 2007; Lai, Calandra & Ma, 2009; Ma & Harmon, 2009). Furthermore, according to Parker (2011), design-based research is gaining prominence in the field of education due to its ability to amalgamate research, design, and practise into a unified process, thereby yielding practical outcomes that are firmly rooted in a theoretical framework (Bowler & Large, 2008, p. 39). Moreover, it is widely acknowledged in the scholarly literature that design-based research is a recognised approach to doing research (Herrington, McKenney, Reeves & Oliver, 2007; O'Donnell, 2004; Wang & Hannafin, 2005). The unanimity on the definition of design-based research was further supported by the Design-Based Research Collective (2003), which described it as a “methodological approach that connects theoretical research with educational practices” (p. 8).

From the turn of the 20th century, design-based research (DBR) emerged as a novel research methodology. DBR is grounded in reality and focuses on examining a specific intervention through iterative design, enactment, analysis, and redesign (Brown, 1992; Cobb et al., 2003; Collins, 1992). The intervention may take the form of an instructional strategy, a type of assessment, a learning activity, or technological intervention, in which the effectiveness of a particular learning environment or tool is determined (Anderson & Shattuck, 2012). The DBR explains how designs work in real-world settings and how to better understand the teaching and learning issues involved (DBRC, 2003). As an emerging paradigm, DBR demonstrates how design principles evolved, as well as the types of interventions that can result in improved outcomes. By associating processes with outcomes in specific contexts, DBR can gain a better understanding of the intervention and contribute to the development of more accurate theoretical accounts (DBRC, 2003).

Regardless of the various names attributed to design-based research in the literature (Andriessen, 2007; Brown, 1992; Cobb et al., 2003; Collins, 1992; Freudenthal, 1988; Gravemeijer, 1994; Lijnse, 1995; Plomp, 2007; Romberg, 1973; Van den Akker, 1999; Van den Akker et al., 2006; Wang & Hannafin, 2005), it has been established that the underlying principles and techniques are universally applicable (Wang & Hannafin, 2005). Unlike experimental research, DBR is not concerned with the controlled application of theories, designs, and models. Rather than that, it seeks to improve both theory and the educational context, which is viewed as a chaotic reality that should be studied in its entirety (Armstrong, Dopp &Welsh, 2020). They believed that learning is a human, social phenomenon that cannot always be effectively studied using the same scientific and objective standards used to study physical phenomena. Thus, throughout this study, the term "design-based research" will be used because it is the most frequently used term in literature, and, as the DBRC (2003) noted, its use helps avoid confusion with "design studies."

Design-based research is not so much an approach as it is a collection of approaches aimed at developing new theories, artefacts, and practices that account for and potentially influence learning and teaching in naturalistic settings. The literature contains numerous definitions of design-based research. For instance, Shavelson, Phillips, Towne, and Feuer (2003, p. 25) stated that design-based research is "strongly grounded in prior research and theory and conducted in educational settings." It seeks to "trace the evolution of learning in complex, messy classrooms and schools, test and build theories of teaching and learning, and produce instructional tools that withstand the challenges of everyday practise." Additionally, Barab and Squire (2004) defined design-based research as "a collection of approaches aimed at developing new theories, artefacts, and practices that account for and potentially impact learning and teaching in naturalistic settings" (p. 2). Wang and Hannafin (2005) also defined it as "a systematic but adaptable methodology for improving educational practices through iterative analysis, design, development, and implementation, based on collaboration between researchers and practitioners in real-world settings and resulting in contextually sensitive design principles and theories" (p. 67). Plomp (2013, p. 4) further defined educational design research as a "systematic study of designing, developing, and evaluating educational interventions (programmes, teaching-learning strategies and materials, products, and systems) as solutions to complex problems in educational practice, to also advance our knowledge about the characteristics of these interventions and the processes by which they are designed and developed". Design-based research is a research methodology developed by and for educators to enhance the impact, transfer, and translation of educational research into improved practice. Additionally, it emphasises the importance of theory development and the creation of design principles that guide, inform, and improve practice and research in educational settings (Anderson & Shattuck, 2012). Cobb et al. (2003) assert that design-based research entails both engineering" specific modes of learning and conducting systematic research on those modes of learning within the context defined by the means of support. This designed context is tested and revised, and the subsequent iterations serve a similar function to systematic variation in experiments. The attributes of design-based research render it particularly suitable for addressing challenges characterized by openness and an ambiguous initial problem statement (Kelly, 2010; van den Akker, 1999). Based on the criteria provided earlier, it is evident that the process of generating theories is an outcome of design-based research, as indicated by Plomp (2013), van den Akker (1999), and Wang & Hannafin (2005).

Design-based research, as described by Sari and Lim (2012), seeks to tackle intricate issues within educational environments (p. 2). Its primary objective is to enhance the relationship between educational research and practical challenges, as highlighted by Amiel and Reeves (2008) (p. 34). Additionally, "design-based research aims to facilitate the creation and advancement of prototype solutions for complex, context-specific problems," as emphasised by Lai et al. (2009, p. 120). Design-based research (DBR) has been shown to yield diverse outcomes (DBRC, 2003; Juuti & Lavonen, 2006). One of the potential results is the formulation of design principles (Bowler & Large, 2008; Juuti & Lavonen, 2006) that "may be utilised by anyone with an interest in investigating comparable contexts and issues (Amiel & Reeves, 2008, p. 35) in order to resolve intricate educational challenges." Moreover, it can provide advantageous methodological instruments for researchers endeavouring to appreciate diverse factors inside a naturalistic framework. Furthermore, it is worth noting that design-based research has the potential to generate novel theories or enhance the advancement of pre-existing ones (Bowler & Large, 2008; Juuti & Lavonen, 2006). However, Amiel and Reeves (2008, p. 35) argue that "the generation of new theories can only transpire through prolonged involvement and numerous design investigations." According to Barab and Squire (2004, p. 5), "design-based research necessitates more than mere demonstration of a design's efficacy. It entails the researcher's responsibility to produce evidence-based assertions regarding learning that tackle current theoretical concerns and contribute to the advancement of theoretical knowledge in the field."

Plomp (2013) suggests that design-based research has three discrete phases, namely fundamental research, prototyping, and evaluation. According to Plomp (2013), the preliminary stage of research involves many sub-stages, including the exploration of needs and context, the evaluation of relevant literature, and the scrutiny of curriculum materials. The combination of these sub-stages plays a crucial role in the development of a conceptual framework for the study. This framework then enables the discovery and use of pertinent principles to effectively handle the research topic. During the prototype phase of design-based research, a series of iterative cycles are undertaken to design and create an intervention aimed at resolving a specific educational issue. Plomp (2009) asserts that the utilization of iterations facilitates the enhancement of interventions in the developmental process and the refinement of design ideas. The prototype phase largely focuses on formative evaluation and reflection. This is due to the likelihood of the intervention encountering difficulties and experiencing a lack of success during its first implementation, therefore requiring the need for some components of the intervention to be revised (Antwi, 2013). Iterative development is a methodology that aims to achieve a harmonious equilibrium between the stated objectives and the actual outcomes (Plomp, 2013). Summative evaluation activities are often carried out during the assessment phase of design-based research to determine the quality of the intervention being studied. According to Kelly (2013), the evaluation process in design-based research does not always prioritize the mere summarization of students' learning outcomes. However, it is important for researchers to include not just the repeated examination of the effects of prototyping but also the methods employed to assess these effects. In other words, the effectiveness of the intervention may be inferred from its ability to fulfil the predetermined criteria. Furthermore, the utilization of summative evaluation outcomes is commonly employed to enhance the efficacy of the intervention (Plomp, 2013).

Design-based research (DBR) is a research approach that focuses on the design and development of interventions in real-world settings (Plomp, 2013). In the context of educational research, DBR is particularly suitable when a single study is insufficient to address a complex problem faced by the research community (Mckenney & Reeves, 2013; Walker, 2006). Additionally, DBR is appropriate when practitioners, such as teachers, lack pedagogical content knowledge, and when the implementation of a solution to an identified educational problem is anticipated (Kelly, 2013). Moreover, the utilization of design-based research is particularly suitable in situations where there is a need to assess both the intervention and the procedures employed in its design and creation (Antwi, 2013). This approach is also advantageous when there is a requirement to identify practical resolutions to research inquiries (Cobb et al., 2003), and when governmental bodies are faced with the implementation of demanding educational reforms that will have substantial long-term consequences (Plomp, 2013). The process of designing, researching, and developing a paradigm is primarily represented by the delineation of distinct phases or steps. While the various models of processes proposed by various authors (Mckenney & Reeves, 2013; Reimann, 2010) differ in terms of the number of phases and notional descriptions, their fundamental structures exhibit a high degree of similarity. Iterative cycles of design, testing, analysis, and redesign are used to carry out the research and development process. Within these cycles, the design is optimised incrementally, and the development processes and principles are documented concurrently. "Another distinguishing feature of the design experiment methodology is that the research team gains a better understanding of the phenomenon being investigated while the experiment is being conducted" (Cobb et al., 2003, p. 12).

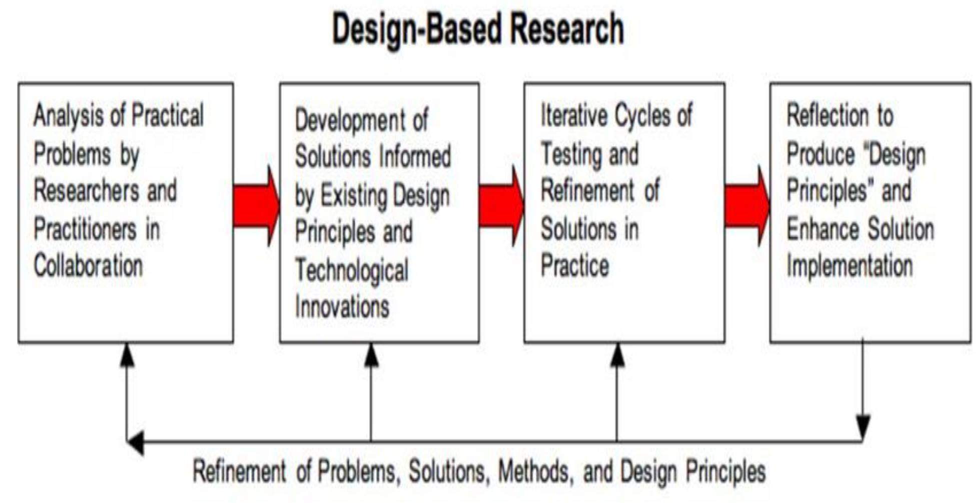


Figure 2: A diagram showing the processes involved in designed based Research (Reeves, 2006).

According to Wang and Hannafin (2005), design-based research is a methodological approach that is both methodical and adaptable, with the objective of enhancing educational practices via a process of iterative analysis, design, development, and implementation. This approach emphasizes the importance of cooperation between academics and practitioners in real-world situations. As stated by Barab and Squire (2004), the implementation of DBR goes beyond the mere presentation of a specific design. It necessitates the researcher to surpass a singular design example and instead produce claims about learning that are grounded in evidence. These claims should address current theoretical concerns and contribute to the theoretical understanding within the field. According to Van den Akker, Gravemeijer, McKenney, and Nieveen (2006), the utilization of a design research approach is highly recommended in research projects due to its ability to enhance the applicability of research findings in educational policy and practice. This approach involves the development of empirically grounded theories through a comprehensive examination of the learning process and the various means that facilitate and strengthen it. Ultimately, the adoption of a design research approach contributes to the refinement and effectiveness of design practices. The methodology employed in this study is characterized by an iterative process that encompasses the stages of analysis, design, and assessment. A study was undertaken to get insights into the strategies for effectively targeting a design (McKenney, Nieveen & Van den Akker, 2006). According to Cobb et al. (2003), design-based research projects exhibit several shared characteristics. These include the generation of theories pertaining to learning and teaching, the incorporation of interventionist elements through design, the occurrence within naturalistic settings, and the iterative nature of the research process. Evaluation serves two main purposes: formative and summative. Formative evaluation is conducted with the aim of enhancing the quality of prototypes, as highlighted by McKenney et al. (2006). On the other hand, summative evaluation is carried out to assess the overall impact of the intervention. These underlying reasons serve as a framework for contemplating design-based research. Moreover, Reeves (2006) illustrates the DBR approach as a systematic procedure that commences with the identification and analysis of issues by researchers and practitioners working together. Subsequently, this approach progresses by developing prototype solutions that are informed by theories, established design principles, and technological advancements. It then entails iterative cycles of testing and refining these solutions in real-world settings. Ultimately, the DBR approach culminates in reflection, leading to the formulation of design principles and the improvement of solution implementation in practical contexts. The DBR model proposed by Reeve (2006) will be employed in this study because of its capacity to facilitate the iterative improvement of issues, solutions, and approaches across the many stages of the DBR process.

According to Plomp (2013), design research that has yielded a validated and effective intervention and design principles can be followed by effective studies with a focus on upscaling the intervention to a broader context, thereby aiming to test design principles in a broader domain. Variations in the objectives of design research, such as validation studies versus development studies, allow for further differentiation between design studies (see Van den Akker, Gravemeijer, et al., 2006). Validation studies emphasize the design of learning environments or trajectories to develop and validate theories about the learning process and the design of learning environments. Validation research aims to advance learning and instruction theories, including:

1. micro-theories: the instructional activity level
2. domain-specific instruction theories: at the level of pedagogical content knowledge;
3. local instruction theories: at the level of the instructional sequence. (Gravemeijer & Cobb, 2006)

In validation studies, researchers do not work in controlled environments; rather, they utilize the natural classroom setting as "test beds." Typically, the following phases comprise validation studies (Gravemeijer & Cobb, 2006, p. 15):

"

1. environment preparation: developing a preliminary instructional design based on an interpretive framework;

2. classroom experiment: testing and improving the instructional design or local instructional theory and developing an understanding of how it works;
3. retrospective analysis: analysing the entire data set to contribute to the development of a local instructional theory and (improvement of) the interpretive framework."

DiSessa and Cobb (2004, p. 83) caution that "design research will not be particularly progressive if the motivation for conducting experiments is limited to developing domain-specific instructional theories." However, "the practical contribution lies in the development and implementation of specific learning trajectories to test the design's theoretical foundation" (Nieveen, 2013, p. 153)

The purpose of development research is to distil actionable design ideas for use in developing cutting-edge pedagogical interventions. Education innovations may be honed by testing in the field and improved with the help of development studies (Nieveen, 2013). By breaking down the design process, useful design concepts are uncovered that may guide subsequent development and implementation choices (Plomp, 2013). According to Van den Akker (1999), there are two main types of design principles:

"

1. procedural design principles, which pertain to the design process;
2. substantive design principles, which pertain to the design itself" (p. 23).

Despite the conceptual importance of differentiating validation and development studies, many studies with an eye towards improving educational practise also seek to build and validate ideas (design principles). Successful programme dissemination and execution are the intervention, while the process of methodical reflection and documentation yields a set of processes and conditions for such outcomes (the design principles). It is possible that in practise, researchers in the field of design will integrate the two approaches (DBRC, 2003). This study used the two Design-based research orientations to enhance organic chemistry education.

Summary of Reviewed Literature

Constructivism is a theoretical approach to learning that emphasises the active construction of knowledge by humans. It includes five types of learning: situated cognition theory, activity theory, experiential learning, and instructive and authentic learning. These schools of constructivism share principles such as the idea that learning is an active process rather than a passive one.

In organic chemistry, students often struggle with understanding abstract concepts due to limited memory space. To improve their academic success, it is crucial to foster students' ability to understand organic concepts and develop positive attitudes towards the subject. Chemistry is a visual science that relies heavily on symbolic language to convey ideas, and students' ability to solve chemical problems is tied to their ability to interpret these representations.

Many students struggle with identifying isomers due to a lack of comprehension of structural representations of organic molecules. Understanding the correlation between molecular structure and physical and chemical characteristics is essential for grasping subjects like organic chemistry. The perception of organic chemistry as a topic that relies heavily on memory can be attributed to the inability of students to use structural clues to deduce the mechanisms and rationales behind molecular interactions.

Instructional design (ID) is a systematic process that stimulates appropriate cognitive processes in learners and contributes to more successful learning outcomes. ID models are visual representations of the instructional design process, focusing on goal setting, teaching, and learning strategies, technology selection, educational media identification, and performance assessment.

This study aims to improve the teaching and learning of organic chemistry among science students in Senior High Schools (SHS) in Ghana through the development of a Theory-based Organic Chemistry Instructional Plan (TB-OCIP). The primary methodology used is Design-Based Research (DBR), which guides the development of the instructional design. Gagne's instructional model is one of the most widely known and used instructional models in the field of instructional design. Situated learning, a concept defined by Brown, Collins & Duguid (1989) and elaborated by Lave and Wenger (1991), emphasizes the importance of knowledge being presented in an authentic setting. Formative assessment, such as Data-Based Decision Making (DBDM) and Assessment for Learning (AfL), focusing on the quality of the learning process rather than its outcomes. Video-based learning (VBL) is an effective learning method that enhances students' acquisition of skills and comprehension of procedures. Design-based research demonstrates how design principles evolved and the types of interventions that can result in improved outcomes. It aims to improve educational practices through iterative analysis, design, development, and implementation. Validation studies emphasize the design of learning environments or trajectories to develop and validate theories about the learning process. This study employs two Design-based research orientations to enhance the pedagogy and acquisition of knowledge in the field of organic chemistry.

CHAPTER THREE

RESEARCH METHODS

The present study employed a design-based research approach to facilitate the development of conceptual understanding in the context of studying organic chemistry among science students in senior high schools. To do this, an alternative method of teaching was used. The researcher used a design-based research strategy to create and test a new approach of teaching organic chemistry in senior high schools and then assess the intervention's impact on the students' understanding of organic chemistry. Research design, population, sampling technique, data collecting tools, data collection procedures, and data processing and analysis are all be discussed in depth below.

Research Design

A design-based research approach was adapted for this study. The present study employed a design-based research approach, which did not prioritise design over research or vice versa (DBRC, 2003). According to DBRC (2003), "DBR is the methodology to adopt when a study is aimed at understanding how, when, and why educational innovations work in practice" (p. 5). The utilisation of DBR was deemed suitable for enhancing the instruction and comprehension of organic chemistry among secondary school science students due to its primary purpose of enhancing educational practise rather than validating it (Reeves, 2006). According to the literature, DBR is a method that seeks to improve educational practise through iterative analysis, invention, development, and implementation, is grounded in collaboration between researchers and practitioners in real-world settings, and yields design principles and theory that are sensitive to context (Feng & Hannafin, 2005). Based on these standards, DBR's suitability for facilitating the design process that led to theory development in this investigation was established. To evaluate the intervention's efficacy in real-world contexts, the chosen DBR method was extended beyond its original scope of covering only the intervention's design and testing.

The study employed a design-based research approach, drawing upon the adapted iterative design framework developed by Reeves (2006) as seen in Figure 1. This framework was further adjusted to suit the specific requirements of the current research. Reeves' conceptualization of the stages inherent in a DBR framework emphasises the critical role of feedback in facilitating the iterative nature of the method. Specifically, the feedback obtained from each step of the design process serves as a valuable guide for enhancing the overall quality of the intervention. Furthermore, as seen in Figure 1, the input not only impacted the efficacy of the intervention created, but also played a crucial role in informing the enhancement of the design principles. This affected positively the quality of the intervention, the design principles, brought about a profound understanding of the phenomenon of the study (Euler, 2014). Based on Reeve (2006) framework, a four-phase DBR approach adapted for this study is presented in Figure 3.

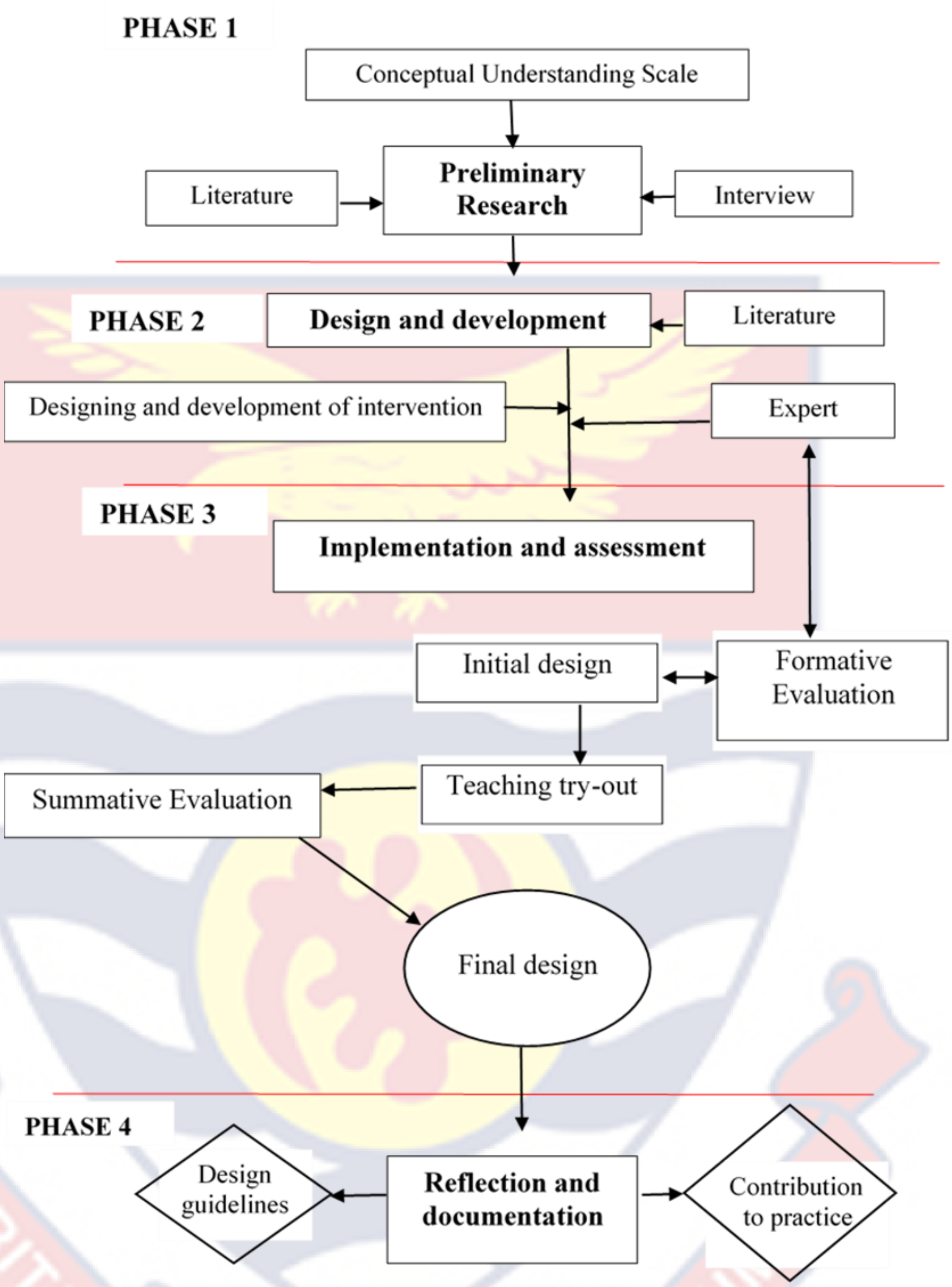


Figure 3: A four-phase DBR adapted for the study (Reeves, 2006).

Phase 1: Preliminary research

Preliminary research was centred on reviewing the literature on teaching and learning organic chemistry. The areas of the literature review were students' conceptions; constructivism, challenges in learning organic chemistry; students' attitude towards learning organic chemistry; instructional design; sources of conceptual difficulties in organic chemistry; theoretical design framework; and design-based research. The review contributed to the partial elucidation of the issues pertaining to the instruction and acquisition of organic chemistry. Moreover, the initial investigation involved conducting a needs assessment in order to identify the educational difficulties related with the instruction and acquisition of knowledge in the field of organic chemistry at the secondary high school level. A series of interviews was carried out with teachers who specialise in teaching chemistry and senior high school science students. The interviews aimed to gather their perspectives on the difficulties, requirements, and potential advantages related to the instruction and acquisition of knowledge in organic chemistry. Furthermore, the researcher devised an assessment tool known as the Organic Chemistry Conceptual Understanding Scale-1 (OCCUS-1), which was employed in a cross-sectional survey to investigate students' comprehension of organic chemistry concepts. The findings from the OCCUS-1 study and subsequent interview sessions provided light on the current state of teaching and learning organic chemistry in senior high schools (SHS) in Ghana, providing valuable insights into the challenges connected with this subject. The design and development of an intervention for teaching and learning organic chemistry in the secondary school setting (SHS) were influenced by this information.

Phase 2: Design and development

This phase consisted of three components: Literature review, designing of intervention, and expert appraisal. Based on the outcome of the preliminary research in Phase 1, the researcher conducted a literature review to facilitate the establishment of guidelines that informed the selection of an alternative intervention. The areas of the literature review were constructivism, instructional design, situational learning, formative assessment, and video-based learning. The interventional tool was sent to specialists for evaluation in order to ascertain its use and enhance its validity. The experts in question possessed expertise in the fields of instructional design and chemistry teaching. The perspectives and suggestions from these experts were factored into the designing of the instructional tool to improve its quality. Therefore, the evaluation conducted by experts played a crucial role in refining the intervention and the design principles to optimise its effectiveness.

Phase 3: Implementation and assessment

Phase 3 of the study focused on the effectiveness and functionality of the proposed alternative intervention in a naturalistic setting. This phase consisted of teaching try-outs (iterative cycles) to refine the developed instructional tool. The final design of the instructional tool was implemented with second-year SHS science students over a period of 6 weeks. The study employed an iterative qualitative approach due to its capacity to generate comprehensive data that is mostly inductive in nature. During the schedule, the researcher organised five lessons on difficult concepts identified in the Preliminary research using the TB-OCIP. Further, the students were made to complete an exit card and participate in group interviews following each lesson. The sole purpose of the exit card and group interview was to facilitate information gathering on students' perspectives and experience on the use of the instructional tool in teaching and learning organic chemistry to facilitate the modification and refining of the TB-OCIP.

The study employed a single group pre-test-post-test quasi-experimental design (Cohen et al., 2011; Marsdena & Torgersonb, 2012). The purpose was to determine the improvement in students' conceptual understanding of organic chemistry as they learnt through the use of the alternative instructional strategy. An intact SHS 2 science class was selected to be treated with the intervention. Thus, single-group comprising science students in an intact class, from a selected school that had not treated organic chemistry aspects selected for the treatment, were engaged, and subjected to measurement before and after the five lessons. The test items making up of two-tier multiple-choice items and short answers were developed and used for the pre-test and post-test design. Two equivalent forms of the test items based on concepts taught with the alternative instructional strategy were used to conduct the pre-test and post-test. The rationale of the single group pre-test-post-test quasi-experimental measurement during the lesson presentation was to gather data to ensure comparability and the determination of the immediate effect of the intervention on students' conceptual understanding of organic chemistry.

Phase 4: Reflection and documentation

Phase 4 of the design was reflection on the whole process from design and development, teaching try-outs, and documentation of the study. The objective of this study was to assist the researcher in doing a retrospective analysis of the design, development, and implementation of the whole process, as well as to evaluate the intervention as a potential method for enhancing the teaching and learning of organic chemistry among secondary school science students.

Study Area

The study area was the Kumasi Metropolitan Assembly (KMA), situated within the Ashanti region, the third largest of 16 administrative regions in Ghana. KMA, an administrative district among the 52 in the region, holds the accolade of being the second biggest and most densely populated city in Ghana, second only to the national capital, Accra. Its altitude varied from 250 to 300 metres above sea level and its latitude from 6.35°N to 6.40°S and its longitude from 1.30°W to 1.35°E. In the north, the Metropolis is bordered by Kwabre East and Afigya Kwabre Districts; in the west, it is bordered by Atwima Kwanwoma and Atwima Nwabiagya Districts; in the east, it is bordered by Asokore Mampong and Ejisu-Juaben Municipality; and in the south, it is bordered by Bosomtwe District. Located around 432 kilometres north of Accra, KMA has a total size of roughly 214.3 square kilometres, or about 0.9% of the total land area in the region. Surprisingly, it is home to 36.2% of the region's population, consisting of 443,981 people (213,662 men and 230,662 females) (Ghana Statistical Service, 2021). Wet sub-equatorial climate best describes the Metropolis, which has average lows of 21.5°C and highs of about 30.7°C. KMA is located in the wet semi-deciduous South-East Ecological Zone of the transitional forest. The region's lush vegetation, prominently showcased species such as Ceiba, Triplochlon, and Celtis, contributed to its well-deserved name the "Garden City of West Africa." Urban agriculture took precedence within the KMA, focused notably on the cultivation of vegetables like carrots, cabbage, lettuce, and green onions. The dominant ethnic group was the Asante, accounting for 80.7% of the population, followed by the Mole-Dagbon (8.7%) and the Ewe (3.6%).

The Metropolis also played host to various other ethnic groups found across Ghana. Kumasi boasted an extensive array of educational institutions, including 17 senior high schools, 1 technical high school, 2 commercial schools, and 1 nursing training school in addition to 10 tertiary institutions. The motor vehicle and motorcycle industry employ the largest share (38.4%) of the working population, closely followed by the manufacturing industry (13.6%). Undoubtedly, Kumasi Metropolis stood as a prominent hub of African culture and traditions, both within Ghana, Africa, and the global context. The Metropolis drew tourists due to attractions such as the Manhyia Palace, a historic seat of the Asante Kingdom that dates back to the 17th Century, solidifying its reputation as a vibrant tourist destination within the Ashanti Region.

Population

The study was carried out in Senior High Schools located in the Ashanti Region of Ghana. The region was made up of one metropolitan, 18 municipals, and 33 district assemblies. In the Preliminary research phase, the population comprised all SHS 3 science students and chemistry teachers in the Kumasi metropolitan area, which had a total number of 17 public and two private Senior High Schools. At the Preliminary phase, the SHS 3 science students and their teachers were used in the study because the former had been taught organic chemistry. According to MOE (2010), organic chemistry was expected to be taught at the SHS 2. This meant that SHS 3 science students possessed the desired traits needed for the study. Also, SHS 3 students had been adequately exposed to teaching and learning chemistry over a longer period to enable them provide vital information on the barriers and needs in teaching and learning organic chemistry. Chemistry teachers with repeated experience in teaching organic chemistry had in-depth knowledge about the difficulties in teaching and learning organic chemistry (Kini & Podolsky, 2016). At the Implementation and Assessment phase of the study, SHS 2 science students were used. This is because the SHS 2 students were expected to be introduced to organic chemistry at this level as prescribed in the SHS chemistry curriculum (MoE, 2010).

Sampling Procedure

In the Preliminary research phase of the study, Kumasi Metropolis was conveniently selected as the study zone. Kumasi Metropolis was selected because it had the largest number of SHS in Ghana compared to any other district and also for a cost-effective measure aimed at optimising data collection efforts and minimising expenditures related to sampling and data gathering. Amongst the SHS 3 students in each school, a simple random sampling procedure (Alvi, 2016; Cohen et al., 2011) was used to select students to participate in this study. Simple random sampling was used because each science student within the Kumasi metropolitan area was given an equal chance of selection to participate in this study. Averagely, most of the schools in Kumasi metropolis had three intact science classes. According to Gill, Johnson, and Clark (2010), for a descriptive survey, it was appropriate to sample approximately 16% of students for the study. This assertion was also supported by Krejcie and Morgan (1970). Similarly, Gay (1996) asserted that in descriptive research, the corresponding general guideline was to sample 10% to 20% of the population. Hence, there were 17 public SHS to select the desired sample size of science students from. It was assumed that seven intact elective science classes were sufficient with an average number of 48 science students per class. Seven intact classes were subsequently selected randomly from a randomly selected seven schools offering the General Science programme to students to obtain the desired sample size of 276 science students from them. Also, all the teachers teaching chemistry in the SHS 3 classes (at least within the last 5 years) were selected purposively to take part in the teachers' interview schedule.

Further, some of the science students from the randomly sampled class were purposively sampled after responding to the OCCUS-1 to participate in the students' interview schedule. Purposive sampling was used to ensure that science students with the desired traits which was essential to the conduct of the research were selected. The selection of science students was determined by their performance score on OCCUS-1, which assessed their conceptual understanding. Thus, both high- and low-performing science students were engaged in the student interview schedule. Guest, Bunce, and Johnson (2006) and other researchers, Coenen, Stamm, Stucki, and Cieza (2012); Francis, Johnston, Robertson, Glidewell, Entwistle, and Eccles (2010) found that about 12 to 16 interviewees were adequate to achieve thematic saturation. Similarly, Hagaman and Wutich (2017, p. 1) found that "they could reliably retrieve the three most salient themes from each of the four sites in the first 16 or fewer interviews." Hence, 14 science students (comprising science students who scored above average, and below average) were selected to respond to the students' interview schedule. In the Implementation and Assessment phase of the study, an intact SHS 2 science class was randomly sampled from the list of schools that responded to OCCUS-1.

Data Collection Instruments

Organic Chemistry Conceptual Understanding Scale – 1 (OCCUS-1)

In this study, OCCUS-1 developed by the researcher was used to collect data at the Preliminary research phase on conceptual understanding of organic chemistry amongst SHS 3 science students. OCCUS-1 was used in this context because of its inherent capacity to determine students' conceptual understanding and difficulties in learning organic chemistry concepts. This facilitated the development and designing of an alternative instructional intervention to improve the teaching and learning of those concepts in organic chemistry. OCCUS-1 consisted of two-tier multiple-choice items with an open-ended (MC-OE) option for students to give reasons for the selected option. The second part of OCCUS-1 consisted of short answer items requiring students to provide short responses to the questions asked and give reasons for their responses. OCCUS-1 was made up of 42 items. The 42 items consisted of 12 two-tier MC-OE and 30 short answer items (Appendix A). The test items on OCCUS-1 were prepared based on analysis of science students' difficulties in conceptual understanding of hydrocarbons and derived hydrocarbons as reported in the WAEC chemistry chief examiner's reports. The concepts were: reactions of organic compounds (7 items), isomerism (5 items), naming and drawing organic compounds (18 items), identification of functional groups (8 items), physical and chemical properties (4 items).

Organic Chemistry Conceptual Understanding Scale – 2 (OCCUS-2)

At the Implementation and assessment phase of the study, Organic Chemistry Conceptual Understanding Scale - 2 (OCCUS-2) was developed by the researcher and administered as a pre-test and post-test to examine SHS science students' improvement in conceptual understanding of organic chemistry after the implementation of the intervention. OCCUS-2 was made up of a two-tier diagnostic test consisting of multiple-choice items with an open-ended (MC-OE) option for students to give reasons for the selected option in the first part. The second part of OCCUS-2 was made up of short answer items requiring students to provide short responses to the questions asked. OCCUS-2 was in two different forms, ‘A’ and ‘B’ with the test items on B varied on the same concept that was used to conduct the pre-test (OCCUS-2A) (see APPENDIX B) and post-test (OCCUS-2B) (see APPENDIX C). The OCCUS-2A and OCCUS-2B were made up of 9 two-tier MC-OE and 1 short answer items. The test items were developed based on how well the students demonstrated conceptual understanding on these concepts during the preliminary phase: reactions of organic compounds (2 items), isomerism (2 items), naming, and drawing of organic structures (2 items), identifying functional groups (2 item), and the physical and chemical properties (2 items) of organic compounds.

Validity and reliability of tests: The researcher consulted the Ministry of Education's (2010) chemistry curriculum in order to ensure that the items included in the study were aligned with the organic chemistry topics that students are expected to learn, as well as the thinking skills that are promoted in the curriculum. This was done to guarantee that the content of the items was valid. Also, to establish both face and content validity, the three instruments were given to two highly experienced WAEC Assistant Examiners who specialise in teaching chemistry at the Senior High school level, as well as two specialists in teaching chemistry education from the

University of Cape Coast. These individuals were selected to provide their expert judgement on the content of the instruments. The recommendations provided by the expert were implemented in order to enhance the overall quality of the test items on OCCUS-1, OCCUS-2A, and OCCUS-2B.

The OCCUS-1 (used at the Preliminary research phase) was pilot-tested with an intact class of SHS 3 students and OCCUS-2A and OCUS-2B (used at the Implementation and assessment phase) were piloted with an intact class of SHS 2 students in a school located in the Cape Coast metropolis. The test items underwent item analysis. The process allowed for the calculation of the difficulty and discrimination indices of the test items, so contributing to the enhancement of the internal consistency of the instruments.

Kuder-Richardson formula 20 (KR-20) coefficient of reliability was used to calculate the reliability coefficient for the three test instruments because the items were scored as either correct or incorrect. Moreover, the use of the KR-20 was advantageous due to its inherent ability to assess the degree to which test items on the test instruments measure the same underlying construct. The KR-20 coefficients were utilised to assess the reliability of the test instruments' outputs. The coefficient of reliability for the OCCUS-1 items was determined to be 0.96 using the KR-20 method. The KR-20 coefficient demonstrated that the test instrument, OCCUS-1, had a high level of reliability. The OCCUS-2A (Pre-test) and OCCUS-2B (Post-test) KR-20 coefficient reliability were calculated to be 0.63 and 0.68 respectively. In social science research, the calculated reliability coefficients for both tests are acceptable (Fisher, 2007; Ghazali, as cited in Mohamed et al., 2021).

Interview

The study's interview schedules were semi-structured as teacher interviews, student interviews, and implementation and assessment phase student interviews. That is, Organic Chemistry Teachers Interview Schedule (OCTIS) and Organic Chemistry Students Interview Schedule (OCSIS) were conducted for chemistry teachers and SHS 3 science students who took part in responding to the OCCUS-1 in the Preliminary research phase respectively. In addition, Organic Chemistry Intervention Interview schedule (OCIIS) was used during the teaching try-out at the Implementation and assessment phase of the study with SHS 2 science students. The interview schedules were employed to elicit relevant information from teachers teaching chemistry and their students.

There were seven items on OCTIS (see APPENDIX D). The items were used to elucidate information regarding the teaching experience (2 items), teaching strategies (2 items), challenges, and opportunities of organic chemistry teachers (3 items). OCSIS (see APPENDIX E) for the students consisted of six items. The items were used to identify students' justification of their responses to OCCUS-1 (1 item), teaching strategies (2 items), and barriers in the teaching and learning of organic chemistry (3 items). The OCTIS and OCSIS were adapted from Adu-Gyamfi, Ampiah, and Appiah (2017). The semi-structured interview schedules; OCTIS and OCSIS, were utilised because they provided a substantial amount of detailed and rich data regarding barriers, challenges, and opportunities of teaching and learning organic chemistry amongst SHS science students.

Also, OCIIS was employed during the Implementation and assessment phase of the study when there was teaching try-out to gain insight into science student opinions about the instructional tool. OCIIS consisted of five items that were used to gather information on strengths and weaknesses of the intervention. OCIIS provided a different viewpoint, and group consensus, and enabled the clarification of arguments of diverse opinions on the instructional strategy (see APPENDIX F). OCIIS was adapted from Agyei (2012). OCIIS, a semi-structured group interview schedule, was used to obtain opinions from students on the intervention that aided in cataloguing the students' views on the instructional strategy used in the teaching and learning organic chemistry. Also, OCIIS helped to collect relevant information to significantly contribute to the refinement of the instructional strategy.

Exit Cards

During the Implementation and assessment phase of the study, data were, also, gathered after each lesson using a qualitative survey (Exit cards). The survey was pre-structured to determine aspects of the lesson that students considered as interesting during the lesson delivery. The pre-structured survey was adapted from Mitchell (1993) qualitative strategy. In this study, the exit cards were used to pose questions at the end of class, to which a student responded by writing on the card. The researcher then collected the anonymous card as students exited the classroom. This was a simple and efficient way to collect evidence in the classroom (Barker, Pistrang, & Elliott, 2002), as well as a safe and unobtrusive way for students to express their opinions (Owen & Sarles, 2012).

During the intervention, the researcher sought to elicit a variety of student perspectives on the lesson delivery using the instructional tool in the hopes of furthering student conceptual understanding (Jansen, 2010). The exit card was structured as a two-question, brief, qualitative survey. The first part required students to indicate aspects of the lesson that was most engaging and interesting, and the second part required students to provide reasons for their response in the first part. This provided not only confirmation that the instructional tool was generating student interest, but also exploratory data as to why this was the case. This helped to gain insight into the students' thought processes regarding what they found interesting and valuable in the specific organic chemistry lesson. The Exit Card was intended to be completed by students in less than 5 minutes (see APPENDIX G). The survey was administered to students during the last 5 minutes of each lesson by the researcher.

Validity and reliability of OCSIS; OCTIS; OCIIS; Exit Cards: The semi-structured interview schedules (OCSIS, OCTIS, and OCIIS) and pre-structured qualitative survey (Exit Cards) were used as they allowed questioning to be highly adaptable and evolve based on students' and teachers' contributions. The interviews were audio recorded with an electronic recorder as the main source of data logging. This was pivotal as it provided a complete verbal record of events. The items on the OCSIS, OCTIS, Exit Cards, and OCIIS were shown to chemistry educators and instructional design experts to ensure appropriateness of the instruments. The insights and recommendations provided by these specialists were utilised to enhance the calibre of the items included in the interview schedule. During the interview, I ensured that my opinion and experiences did not clash with those of the respondents, and I restricted the transcribed data to that which was offered by the respondents. A concerted attempt was made to include triangulation, in which data were obtained from many sources for this study, in order to ensure trustworthiness of the data acquired with the instruments. Further, the transcribed audio recordings were given to the respondents to review for clarity and accuracy. Furthermore, a seasoned chemistry educator affiliated with the Science Education Department at the University of Cape Coast was engaged to critically evaluate the themes extracted from the transcribed data, with the aim of enhancing their accuracy and precision. The dependability of the interview schedules was ascertained by ensuring that the same basic items with the same order on the interview schedules were used in both the teachers' and students' interview sessions.

Questionnaire

Organic Chemistry Intervention Perception Scale (OCIPS) was constructed by the researcher and used during the Implementation and assessment phase of the study. OCIPS consisted of 18 items on a five-point Likert scale measuring the efficacy of the instrument and perception of the students on the instructional strategy (see APPENDIX H). The items on OCIPS were scored as strongly agree=5, agree=4, neutral=3, disagree=2, strongly disagree=1 for positive items, and scoring reversed for negative items. OCIPS was adapted from Agyei (2012). In this study, the Cronbach alpha reliability coefficient was used to verify the internal consistency of the items on the OCIPS because it is specifically developed to assess the internal consistency of a set of items that are supposed to evaluate a shared underlying construct. The Cronbach alpha reliability coefficient for the OCIPS was calculated as .73. The reported OCIPS reliability coefficient is acceptable for social science research (Fisher, 2007; Fraenkel &Wallen, 1996; Ghazali, as cited in Mohamed et al., 2021)

Field Notes

Field Notes (FN) was used to supplement the study's completion. In this study, Wolfinger's (2002) salience hierarchy approach and scratch notes were utilised. The salience hierarchy technique entailed describing the most notable and intriguing aspects of the study. Due to the subjective nature of the salience hierarchy, the researcher confined the report to the research context when identifying the most significant and intriguing aspects of the study (Wolfinger, 2002). Utilising this approach, the researcher meticulously documented any observed occurrences that came to their attention throughout the duration of data collecting. Scratch notes were the fundamentals of note-taking, and to enable events to be recorded to reflect actual occurrences, an electronic recording device was used to facilitate the immediate documentation of events.

Researcher reflective journal

In this study, the researcher maintained a Researcher Reflection Journal (RRJ) to serve as a record of events during the study. The researcher recorded any hunches and ideas during the implementation of the instructional strategy. RRJ maintained a reflective and literal record of actions and events before, during, and after each lesson. RRJ, according to Janesick (1999), was an excellent tool for understanding precisely what one was doing as a researcher and gaining extensive and open-ended feedback. It is used as a tool for retrospective analysis, which was essential to DBR and also functioned as a memory aid. In this study, an electronic recording device was used to record researcher's reflections.

Data Collection Procedures

A permission letter of approval, obtained from the Head of the Department of Science Education at the University of Cape Coast, was duly presented to the relevant authorities at the schools where the study was carried out. The primary objective of the letter was to facilitate the researcher in seeking permission and authorization from the school officials to perform the study. The relevant authorities were provided with a comprehensive overview of the study's objectives and the potential advantages it may bring to schools and the broader field of organic chemistry education within the nation. Subsequently, the researcher arranged a briefing session for the chemistry teachers and students at the designated schools in order to elucidate the objectives, significance, and methodology of the study. This measure was implemented in order to mitigate any potential disruptions caused by school activities during the period in which the research instruments were administered. The administration of the research instruments, OCTIS, OCSIS, OCIIS, OCCUS-1, OCCUS-2, OCIPS, RRJ, FN and Exit Cards on teaching and learning organic chemistry were executed by the researcher. For the chemistry teachers in the selected schools to see themselves as part of the study, the interview and test instruments were administered in their presence.

The data for the Preliminary research to answer Research Question 1 were collected during the selected institutions' first term as prescribed by GES academic calendar in the 2021/22 academic year. This period was chosen because the students had completed the organic chemistry concepts, which constituted the primary subject matter under investigation. In the first week of the Preliminary research, the researcher conducted interviews with chemistry teachers and senior high school (SHS) 3 science students from seven schools. The interviews were conducted using the Organic Chemistry Teaching and Learning Barriers and Opportunities Survey (OCTIS) for teachers and the Organic Chemistry Student Interview Schedule (OCSIS) for students. The purpose of these interviews was to gather information on the barriers and opportunities associated with the teaching and learning of organic chemistry. The validation of views expressed by the chemistry teachers and students was ensured through follow ups. An analysis was conducted on the perspectives of chemistry instructors about the instruction of organic chemistry. The findings from this analysis were utilised to identify and delineate the specific barriers that impede the teaching and learning processes in the domain of organic chemistry. The insights obtained from interviews with teachers were taken into account and utilised in the design and development of an instructional tool aimed at facilitating the instruction and comprehension of organic chemistry.

During the second week of the Preliminary research of the study, the researcher administered the OCCUS-1 to the SHS 3 science students. Each of the seven schools was visited over the course of four consecutive days. The administration and collection of OCCUS-1 was executed on the same day of the visit in all of the schools. The OCCUS-1 assessment was promptly evaluated subsequent to the giving of the test in order to determine the average scores of the students. The mean scores were used subsequently to facilitate the categorisation of the students into three groupings of varying output performance in organic chemistry. Based on the mean scores, the students were categorised into two distinct groups: above average and below average. A purposeful sampling technique was employed to choose participants from each category for the purpose of responding to the OCSIS. The purpose was to find out what accounted for any student difficulties in responding to OCCUS-1 as barriers to learning organic chemistry. The students were engaged on the OCCUS-1 and OCSIS sessions within the same week. The analysis of students' scores and explanations using the OCCUS-1 instrument aimed to enhance the understanding of barriers and opportunities in the instruction and acquisition of knowledge in the field of organic chemistry. The findings from students' interviews were considered and used to design and develop an instructional tool for teaching and learning organic chemistry.

Research Question 2 was used to determine an instructional strategy that can be designed to improve teaching and learning organic chemistry. To enable the determination of an appropriate instructional strategy, existing literature on teaching and learning organic chemistry was reviewed. This facilitated the designing and development of an alternative teaching and learning approach that enhanced students' conceptual understanding of organic chemistry. This intervention, Theory-Based Organic Chemistry Instructional Plan (TB-OCIP), was such an instructional strategy. TB-OCIP offered students more interactive learning environment. This instructional strategy was designed to empower students to be active participants, self-motivated, develop in-depth learning (conceptual understanding), generate interest (attention), and improve retention of organic chemistry concepts. The sequence of TB-OCIP followed the steps depicted in Figure 4.

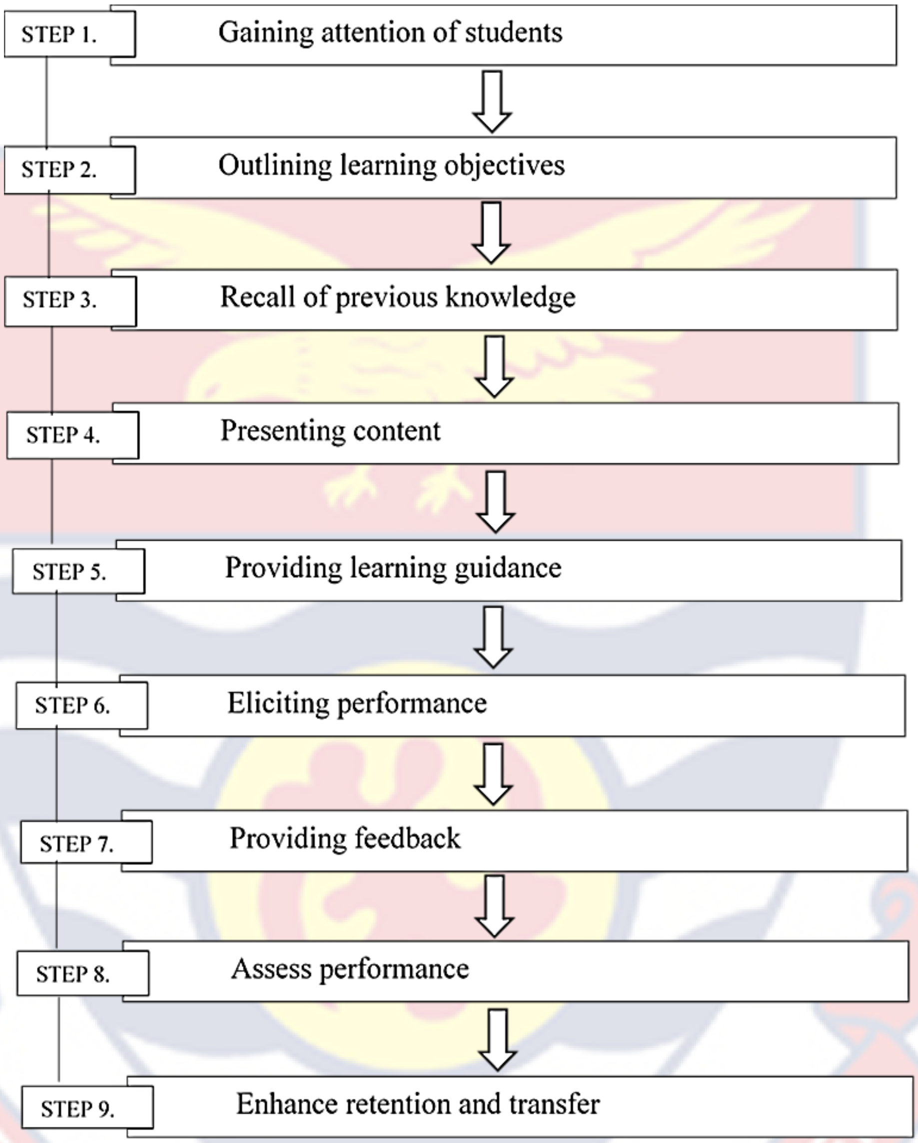


Figure 4: Initial TB-OCIP delivery procedure.

SOURCE: Gagne´ and Brigges (1974)

The preliminary research phase of the DBR study revealed that science students had conceptual difficulties in several areas of organic chemistry. These areas include the ideas of naming and drawing organic compounds, isomerism, reactions, as well as the understanding of chemical and physical properties. Additionally, the identification of functional groups in organic compounds was also shown to be difficult for these students. This suggests that more than a single lesson was organised using TB-OCIP. In this study five lessons (see APPENDIX I) were organised to address naming and drawing, isomerism, reactions, physical and chemical qualities, and identifying functional groups in relation to organic compounds.

Gaining attention: The first step of TB-OCIP consisted of the teacher capturing the students' attention and interest. The purpose was to focus the attention of students on the teaching-learning process (Gagne et al., 2005). The students were primed to receive the incoming information as attention stimulated students' interest and motivated learning (Driscoll, 2000) organic chemistry concepts. The students' attention in the teaching and learning transaction was very important ingredient for effective learning (Slavin, 2009). For effective learning to take place, students focused for the incoming instructional activities activated by shifting their priorities through the use of short videos, animations, demonstration, and exploratory questioning (Gagne, et al, 2005; Tofade, Elsner & Haines, 2013).

Outlining learning objectives: For the second step the teacher outlined the objectives of the lesson to the students prior to instructions. This step facilitated the activation of the students' mental process (Gagné et al., 1992). Outlining the objectives informed students about the expected learning outcomes, which heightened students' anticipation and interest. Presenting students with learning objectives conveyed an expectation of the conceptual understanding they were expected to demonstrate at the end of instruction (Gagne et al., 2005) on organic chemistry. This included teacher describing to the students what they were to do at the end of the lesson and how they should apply their newly acquired knowledge in organic chemistry in the real world. This enhanced students' self-efficacy (Gagné et al., 2005) and satisfaction (Slavin, 2011) for being aware of task to be accomplished on organic chemistry beforehand.

Recall of previous knowledge: At this step, the teacher reviewed the previous learning of the students on organic chemistry, which was a fundamental pillar concept in teaching from 'known-to-unknown'. The integration of the previous knowledge and the incoming knowledge combined to enable an attentive, and expectant student to achieve mastery concept in organic chemistry (Tuckman & Monetti, 2011). This directly addressed one of the conditions for meaningful learning of organic chemistry concepts.

Presenting content: At this step, the senses of the learners were activated for effective learning of organic chemistry to take place (Slavin, 2009). The teacher engaged the students through series of activity to present the organic chemistry concept to be taught (Reiser & Dempsey, 2007). In an attempt to present multiple versions of these concepts, the teacher determined and made use of instructional media, to present new content so that students could perceive and retain the new information (Tuckman & Monetti, 2011) on organic chemistry. The teacher employed group work and reorganised the classroom to reflect a situational learning environment. The groups were tasked to work together and share ideas among themselves on the content of organic chemistry presented through the instructional media. The groups were subsequently employed to deliver a presentation of the outcome of their collaboration.

Providing learning guidance: At this step, the teacher provided students with a step-by-step explanation of the strategies required to learn the content to facilitate retention of organic chemistry concepts. To enable students to properly combine the old and new information and properly store it in the long-term memory, they required assistance or direction (Tuckman & Monetti, 2011).

Eliciting performance: at this step, the teacher activated student thinking processing to aid in the internalisation of organic chemistry concepts and to verify correct comprehension of these concepts. The teacher divided the students into groups and gave each group a worksheet with questions related to the concepts covered in class. The students were required to share their ideas and provide answers to the questions in order to solve the problem. This strategy was applied to assess students' conceptual comprehension of organic chemistry. The instructor then requested that each group presented their solutions to the entire class. This allowed the students to exhibit their understanding of organic chemistry concepts to both themselves and their teacher (Tuckman & Monetti, 2011). This was consistent with Thorndike's exercise law, which stated that if an individual practice the new information, the conceptual understanding would improve (Schunk, 2012).

Providing feedback: In this step, the teacher communicated whether the students' presentation of the solution to the questions was correct. Providing immediate feedback for student on their progress had a greater impact on conceptual understanding of organic compounds as it improves comprehension and performance (Slavin, 2009). Feedback from a reciprocal perspective referred to both the information students received about their performance and the information teachers received about the impact of their instruction. Therefore, effective instruction on organic chemistry was enhanced by feedback.

Assessing performance: In this step, the teacher dissolved the groups for students to assume their individual siting position. The teacher provided questions on the organic chemistry concept taught for the students to practice independently. The students' responses were presented and examined to determine the degree of their conceptual understanding in order to diagnose existing issues to provide further assistance.

Enhancing retention and transfer: In this step, the teacher assisted students in gaining expertise and internalising the organic chemistry concepts they had learned to improve retention and transfer. Retention was important in preventing forgetfulness, and it enhanced students' ability to recall the organic chemistry concept at the appropriate time. The transfer of learning presented students with new tasks that require the application of what was learned in situations that are substantially different from those used for the learning itself, such as concept maps (Gagne et al., 2005).

During the implementation and assessment phase of the study, the TB-OCIP (instructional strategy) was utilised for the teaching and learning of organic chemistry during the teaching try-out. OCIIS was used during the teaching try-out to determine students' views and suggestions on the intervention. Semi-structured group interviews were used to collect data on students' views about the intervention. In the conduct of group interviews, the students were put into two groups (GPI-1 and GPI-2). Two of the research questions were used to evaluate the TB-OCIP at this phase of the study.

OCCUS-2A and OCUS-2B were used during the implementation and assessment phase of the study to examine the effectiveness of the TB-OCIP in teaching and learning organic chemistry in a single group pre and post-test quasi experimental study. Also, the students were required to fill an Exit Card at the end of each of the five lessons. The purpose was to determine aspects of the lesson that students considered as interesting during the lesson delivery. Individual students' pre-test and post-test scores were analysed to determine whether their conceptual understanding of organic chemistry has improved.

OCIPS was used during the implementation and assessment phase of the study to determine students' perceptions of the TB-OCIP. Students were engaged to respond to OCIPS to ascertain their views on their perception of the TB-OCIP.

Researcher Reflection Journal and Field Notes were used during the reflection and documentation phase of the study to outline the theoretical and design principles of the TB-OCIP and to understand the process of teaching and learning organic chemistry with the instructional strategy.

Data Processing and Analysis

The data obtained by the research instruments were subjected to analysis employing a mix of descriptive statistics, inferential statistics, and thematic analysis (themes). Under Research Question 1, the analysis of OCCUS-1 involved the utilisation of percentages, means, and standard deviations to ascertain the levels of organic chemistry conceptual understanding among science students. The second part of Research Question 1, OCTIS and OCSIS was analysed using thematic analysis to determine barriers and opportunities in the teaching and learning of organic chemistry.

Research Question 2 sought to identify instructional techniques that can be used to improve teaching and learning organic chemistry based on literature. To construct the instructional technique, a comprehensive evaluation of the existing literature on teaching and learning in the context of organic chemistry was conducted. The instructional tool known as TB-OCIP was designed and developed using the existing literature and the findings obtained during the preliminary study phase of the Design-Based Research DBR approach.

To answer Research Question 3, data from OCCUS-2A and OCCUS-2B were analysed using means, percentages, and standard deviations to determine the effectiveness of the instructional strategy in improving the conceptual understanding of students on organic chemistry. Individual students' pre-test and post-test scores on each of the items were compared to determine any improvement in their conceptual understanding. In the second part of Research Question 3, the Shapiro-Wilk test was used to determine the normality of the distribution of the means of the students' test scores. Shapiro-Wilk test was employed since it is regarded as the most effective normality test (Razali, 2011). Due to the small sample size, it was imperative to ascertain the distribution of scores on OCCUS-2A and OCCUS-2B to identify a suitable statistical methodology. Therefore, the Shapiro-Wilk test was conducted, which revealed that the distribution of scores on OCCUS-2A and OCCUS-2B deviated considerably from normality; $W(22) = .78$, $p = .01$). Based on these results, a nonparametric test, the Wilcoxon signed-rank test, was employed to determine the significance of improvement observed in students' performance in organic chemistry.

The data from OCIIS, OCIPS, and Exit cards were analysed to address Research Question 4. The data obtained from OCIPS was subjected to statistical analysis, specifically utilising percentages, means, and standard deviations, to assess students' perception of the instructional strategy.

All the test instruments (OCCUS-1, OCCUS-2A, and OCCUS-2B), consisting of a two-tier multiple-choice open-ended and short answer method, were scored 1 mark for each correct response in both tiers and a 0 (zero) mark for incorrect responses in either one or both of the tiers (Haslam & Treagust, 1987; Karataş, Köse & Coştu, 2003; Odom & Barrow, 1995; Peterson & Treagust, 1989). Each of the items on OCCUS-1, OCCUS-2A, and OCCUS-2B scales was analysed using presentation and discussion of the percentages, means, and standard deviations of 'incorrect responses', 'partial responses', and 'correct responses.' Hence, students' responses were categorised as 'low response', 'moderate response', and 'high-response' conceptual understanding of organic chemistry when both responses were incorrect, one response was correct, and both responses were correct respectively. In sum, an item had a total score of 2 marks indicating correct response, a total score of 1 mark indicating partial response, and a total score 0 mark indicating incorrect response.

All qualitative data from OCTIS, OCSIS, OCIIS, Exit Cards were analysed thematically to facilitate the detection, analysis, and reporting of data patterns (themes or sub-themes). That is, a qualitative content thematic analysis was performed based on the six-step guidelines (Braun & Clarke, 2006). The six steps involved in this process are as follows: (1) becoming acquainted with the data by engaging in repeated reading (active reading) of the data and actively searching for meaning and patterns; (2) creating initial codes based on the data; (3) identifying themes and sub-themes that redirect the analysis by organising and compiling all pertinent coded data excerpts within the identified themes or sub-themes; (4) evaluating themes or sub-themes by further refining the identified themes or sub-themes; (5) defining and labelling the themes; and (6) composing the final written document. The analysis of qualitative data was facilitated by the utilisation of MAXQDA 2020 software, which allowed for the systematic coding of data on a response-by-response and line-by-line basis.

Ethical Consideration

Multiple measures were implemented to prioritise ethical issues. The Head of the Department of Science Education of the University of Cape Coast was consulted for approval. The department issued a letter authorising me to undertake the study. After the formal letter was issued, I contacted the authorities in the selected schools. Teachers and students used in the study were given a Consent Form (see APPENDIX J) so they could decide whether to participate in the study. This action was undertaken in order to avoid exerting undue pressure on them to engage in the activity. Given that participation was optional, participants were provided with information on the study's objective and were granted the freedom to discontinue their involvement at any given point. No respondent was subjected to coercion, intimidation, or fear in order to elicit compliance. Furthermore, participants were not requested to provide personal identifiers such as names, phone numbers, or anything else that could link the data collection instruments used in the study for reasons of confidentiality and anonymity.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the study's findings, and the research questions for each stage of the design-based research approach that served as a guide for presenting the findings. The results of the study are presented using themes and tables in accordance with the study's research questions. This implies that both qualitative and quantitative results were used to address the research questions. This was done to ensure triangulation of the results to arrive at the key findings. In addition, the chapter presents the discussion of key findings from the study. In this regard, the findings of each research questions are situated in the literature reviewed in Chapter Two of this study.

Students' Conceptual Understanding as a Barrier to Learning Organic Chemistry

Research Question 1 sought to find out teachers' and students' identifiable barriers and opportunities in teaching and learning organic chemistry. The first part sought to find out students' conceptual understanding of organic chemistry as one of the barriers. To address Research Question 1, students responded to OCCUS-1 in the Preliminary research stage of the DBR approach. The mean scores of students in the OCCUS-1 for each of the item are indicated in Table 1. The mean values between ".0 to .4; .5 to 1.4; 1.5 to 2.0" indicate low level (incorrect response), moderate level (partial response), and high level (correct response) of conceptual understanding respectively. Majority of students in the study exhibited conceptual difficulties in organic chemistry concepts. That is, on the reaction of organic compounds, 221(80.3%) students at a mean of .3 (Std.=.470), isomerism, 184(66.8%)

students at a mean of .4 (Std.=.648), naming and drawing organic compounds, 224(80.9%) students at a mean of .3 (Std.=.579), identification of functional groups, 188(70%) students at a mean of .4 (Std.=.559), and physical and chemical properties of organic chemistry, 199(71.9%) students at a mean of .3 (Std.=.613) were at low level of conceptual understanding of organic chemistry concepts. As evidenced by the WAEC reports, the study confirms students' conceptual difficulties in hydrocarbons and derived hydrocarbons (WAEC, 2011; 2012; 2013; 2014; 2015; 2016; 2017; 2018; 2019; 2020; 2021).

Table 1: Levels of Students Conceptual Understanding in Organic Chemistry (N=276)

Concepts/Items	Level of understanding concept						M	Std.
	Incorrect response		Partial response		Correct response			
	N	%	N	%	N	%		
Reactions of organic compounds	221	80.3	38	13.6	17	6.1	.3	.470
2	138	50.0	96	34.8	42	15.2	.7	.730
7	200	72.5	66	23.9	10	3.6	.3	.537
9	149	54.0	71	25.7	56	20.3	.7	.795
15	265	96.0	8	2.9	3	1.1	.1	.265
19a	265	96.0	10	3.6	1	.4	.0	.221
19b	264	95.7	9	3.3	3	1.1	.1	.271
22	271	98.2	3	1.1	2	.7	.0	.198
Isomerism	184	66.8	59	21.6	33	11.6	.4	.648
3	191	69.2	78	28.3	7	2.5	.3	.523
6	148	53.6	68	24.6	60	21.7	.7	.809
8	148	53.6	94	34.1	34	12.3	.6	.700
10								
	188	68.1	37	13.4	51	18.5	.5	.789
20	247	89.5	21	7.6	8	2.9	.1	.418
Naming and drawing organic compounds	224	80.9	43	15.7	9	3.4	.3	.576
12	266	96.4	9	3.3	1	.4	.0	.214
13	227	82.2	45	16.3	4	1.4	.2	.430
17a	152	55.1			124	44.9	1.0	.997
17b	198	71.7			78	28.3	.6	.902
17c	216	78.3			60	21.7	.4	.826
17d	213	77.2			63	22.8	.5	.841
17e	222	80.4			54	19.6	.4	.795
17f	235	85.1			41	14.9	.3	.713
17g	263	95.3			13	4.7	.1	.424

Table: 1(continued)

17h	245	88.8			31	11.2	.2	.633
18a	212	76.8	59	21.4	5	1.8	.3	.474
18b	220	79.7	50	18.1	6	2.2	.2	.467
18c	228	82.6	44	15.9	4	1.4	.2	.427
18d	202	73.2	68	24.6	6	2.2	.3	.499
18e	222	80.4	48	17.4	6	2.2	.2	.463
18f	225	81.5	47	17.0	4	1.4	.2	.435
18g	248	89.9	24	8.7	4	1.4	.1	.363
18h	229	83.0	40	14.5	7	1,4	.1	.458
Identification of functional groups	188	70.0	82	19.1	6	10.9	.4	.559
1	47	17.0	79	28.6	150	54.3	1.3	.759
5	233	84.4	36	13.0	7	2.5	.2	.447
14a	225	81.5	32	11.6	19	6.9	.3	.573
14b	204	73.9	49	17.8	23	8.3	.3	.628
14c	201	72.8	61	22.1	14	5.1	.3	.567
14d	233	84.4	39	14.1	4	1.4	.2	.413
14e	204	73.9	53	19.2	19	6.9	.3	.600
14f	199	72.1	73	26.4	4	1.4	.3	.487
Physical and chemical properties of organic compounds	199	71.9	49	17.8	28	10.3	.3	.613
4	201	72.8	49	17.8	26	9.4	.3	.650
11	182	65.9	60	21.7	34	12.3	.5	.705
16	261	94.6	9	3.3	6	2.2	.1	.338
21	150	54.3	79	28.6	47	17.0	.1	.759

Where n= the total number of students who responded to the items

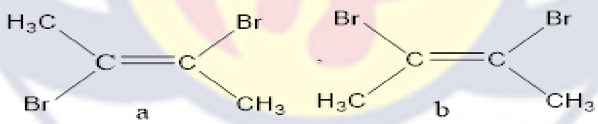
Source: Field data (Gyang, 2021)

Reactions of organic compounds

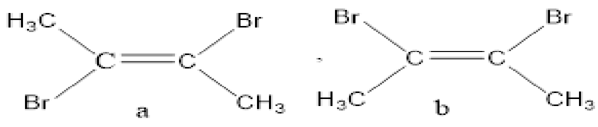
On OCCUS-1, students' understanding of reactions of organic compounds was explored using Items 2, 7, 9, 15, 19a, 19b, and 22 as a likely barrier to learning organic chemistry. With respect to the product formed in the dehydration of an alcohol, "Item 2" was used. From Table 1, the results showed that 96(34.8%) of the students at a mean of .7 (Std.=.730) demonstrated partial response that dehydration of alcohol leads to the formation of an alkene. This indicates that 50% of students gave incorrect response and only 15.2% gave correct response. Hence, students demonstrated moderate level of conceptual understanding of conversion of alcohol to alkene by the process of dehydration. With respect to the starting materials for the preparation of an ester "Item 9" was used. The results showed that 149(58%) of students at a mean of .7 (Std.=.795) demonstrated incorrect response that carboxylic acid and alcohol are the starting materials for the preparation of an ester. This showed that 25.7% of students gave partial response and only 20.3% gave correct response. Hence, students demonstrated moderate level of conceptual understanding of using carboxylic acid and alcohol as the starting materials for preparation of esters. To ascertain the product formed when ethanol is treated with H_2CrO_4, Item 22 was used. From Table 1, 271(98.2%) students at a mean of .0 (Std.=.198) exhibited incorrect response that treating ethanol with H_2CrO_4 converts the molecule to carboxylic. This indicated that 1.1% of the students gave partial response and .7% fully understood and gave correct response. Hence, students demonstrated low level of conceptual understanding of the product formed when ethanol is treated with H_2CrO_4. To ascertain that 2, 3-dichlorobutane is the product formed in the reaction between 2-butene and Cl_2 gas, "Item 7" was used. From Table 1, 200(72.5%) of the students at a mean of .3 (Std.=.537) provided incorrect response that 2,3-dichlorobutane is formed when 2-butene react with Cl_2 gas. This indicated that 23.9% of the students gave partial response whilst only 3.6% understood fully and gave correct response. Hence, students demonstrated low level of conceptual understanding that 2, 3-dichlorobutane is the product formed in the reaction between 2-butene and Cl_2 gas. To determine that H_2/Pd, or Pt is required for the transformation of $CH_3CH{=}CH_2$ to $CH_3CH_2CH_3$, "Item 15" was used. From Table 1, 265(96.0%) of the students at a mean of .0 (Std.=.265) gave incorrect response relating to the fact that H2/Pd, or Pt is a required reagent to transform propene to propane. This showed that 2.9% students gave partial response and only 1.1% fully understood and provided correct response. Hence, students demonstrated low level of conceptual understanding relating to the fact that H_2/Pd, or Pt is required for the transformation of $CH_3CH{=}CH_2$ to $CH_3CH_2CH_3$. To determine that butane is produced when 2-butyne react with excess H_2 gas in the presence of Pt, "Item 19a" was used. From Table 1, 265(96.0%) of the students at a mean of .0 (Std.=.271) provided incorrect response relating to the fact that butane is produced when 2-butyne react with excess H_2 gas in the presence of Pt. This showed that 3.6% of the students gave partial response and only .4% fully understood and gave correct response. Hence, students demonstrated low level of conceptual understanding relating to the fact that butane is produced when 2-butyne react with excess H_2 gas in the presence of Pt. To ascertain that alcohol is the product formed when ethene react with water in the presence of a catalyst (H^+), "Item 19a" was used. From Table 1, 264 (95.7%) of the students at a mean of .1 (Std.=.271) gave incorrect response relating to the fact that alcohol is the product formed when ethene react with water in the presence of a catalyst (H^+). This indicated that 3.3% of the students gave partial response whilst only .05% fully understood and provided correct response. Hence, students demonstrated low level of conceptual understanding in relation to the fact that alcohol is the product formed when ethene react with water in the presence of a catalyst (H^+). In general, the results showed that majority of the students, 221(80.3%) with a mean score of .3 (Std.=.470) provided incorrect response on the reactions of organic compounds which indicates that the students have low level of conceptual understanding in reactions of organic compounds.

Isomerism

To identify an organic molecule which does not exhibit geometric isomerism, "Item 3" was used. From Table 1, 191(69.2%) of the students at a mean of .3 (Std.=.523) gave incorrect response to the fact that 1-hexene undergoes geometric isomerism. This showed that 28.3% of the students gave partial response and only 2.5% provided correct response. Hence, students demonstrated low level of conceptual understanding in identifying an organic molecule which does not exhibit geometric isomerism. To ascertain the similarities between two isomeric forms of a saturated hydrocarbon, "Item 6" was used. From Table 1, 68(24.6%) of the students at a mean of .7 (Std.=.809) provided partial response that two isomeric forms of a saturated hydrocarbon have the same molecular formula. This showed that 53.6% of the students gave incorrect response and only 21.7% of the students fully understood and gave correct response. Hence, students demonstrated moderate level of conceptual understanding in determining the similarities between two isomeric forms of a saturated hydrocarbon. To ascertain that n-hexane and 3-methylpentane are examples of structural isomer, "Item 8" was used. From Table 1, 94(34.1%) of the students at a mean of .6 (Std.=.700) gave partial response that n-hexane and 3-methylpentane are examples of structural isomers. This indicated that 53.6% students provided incorrect response and only 12.3% of the students fully understood and gave correct response. Therefore, students demonstrated moderate level of conceptual understanding of n-hexane and 3-methylpentane as examples of structural isomer. To determine that two given molecules are isomers, 'Item 10" was used. From Table 1, 37(13.4%) of the students at a mean of .5 (Std.=.789) gave partial response that given molecules are isomers. This showed that 68.1% of the students gave incorrect response and only 18.5% fully understood and provided correct response. Therefore, students demonstrated moderate level of conceptual understanding of identification of isomers. To ascertain that the relationship between

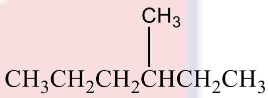


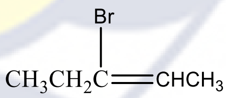
is geometric isomerism, "Item 20" was used. From Table 1, 247(89.5%) of the students at a mean of .1 (Std.=.418) gave incorrect response that relationship between the two given compounds is geometric isomerism. This showed that 7.6% of the students gave partial response and only 2.9% of the students fully understood and provided correct response. Hence, students demonstrated low level of conceptual understanding that the relationship between

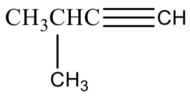


is geometric isomerism. In general, majority of the students, 184(66.8%) at a mean score of .4 (Std.=.648) provided incorrect response which indicate that the students have low level of conceptual understanding of isomerism.

Naming and drawing structure of organic compounds

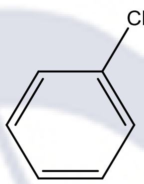
To determine that the IUPAC name of 

as 3-methylhexane, "Item 18a" was used. In Table 1, 212(76.8%) of the students at a mean of .3 (Std.=.474) gave incorrect response to the fact that the given structural formula is 3-methylhexane. This indicated that 21.4% students gave a partial response and only 1.8% students demonstrated full understanding and provided correct response. Hence, students exhibited low level of conceptual understanding of branched-chain alkanes. On "Item 18b", the results in Table 1 showed that 220(79.7%) of the students at a mean of .2 (Std.=.467) gave incorrect response to the fact that 

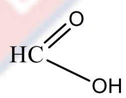
is 3-bromopent-2-ene. This showed that 18.1% of the students provided partial response and only 2.2% fully understood and provided correct response. Hence, students demonstrated low level of conceptual understanding of naming halo-alkenes. On "Item 18c", the results from Table 1 showed that 228(82.6%) of the students at a mean of .2 (Std.=.427) gave incorrect response on the fact that the IUPAC name of 

is 3-methylbut-1-yne. This showed that

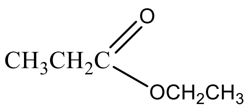
15.9% of the students gave partial response and only 1.4% of the students fully understood and provided correct response. Hence, students demonstrated low level of conceptual understanding of IUPAC naming of branched-chain alkynes. On “Item 18d”, the results from Table 1 showed that 202(73.2%) of the students at a mean of .3 (Std.=.499) provided incorrect response to the fact that the IUPAC name of $CH_3CH_2CH_3$ is propane. This indicated that 24.6% of the students gave partial response whilst only 2.2% students fully understood and gave correct response. Therefore, the students demonstrated low level of conceptual understanding of IUPAC naming of normal alkanes. On “Item 18e”, the results from Table 1 showed that 222(80.4%) of students at a mean of .2 (Std.=.463) provided incorrect response that the IUPAC name of



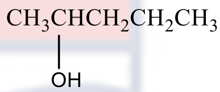
is chlorobenzene. This indicated that 17.4% of the students gave partial response whilst only 2.2% fully understood and provided correct response. Hence, students demonstrated low level conceptual understanding of IUPAC naming of halo benzenes. On “Item 18f”, the results from Table 1 showed that 225(81.5%) of the students at a mean of .2 (Std.=.435) provided incorrect response for the fact that IUPAC name of



is methanoic acid. This indicated that 17.0% gave partial response whilst 1.4% fully understood and provided correct response. Therefore, students demonstrated low level of conceptual understanding of IUPAC naming of normal carboxylic acids. On “Item 18g”, 248(89.9%) of the students at a mean of .1 (Std.=.363) provided incorrect response relating to the fact that the IUPAC name of

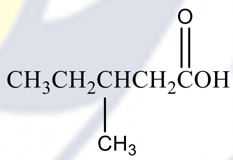


is ethylpropanoate. This indicated that 8.7% of the students gave partial response and 1.4% of the students fully understood and provided correct response. Hence, students demonstrated low level of conceptual understanding on naming an alkyl alkanoate. On “Item 18h”, 229(83.0%) of the students at a mean of .2 (Std.=.458) provided incorrect response relating to the fact that the IUPAC name of

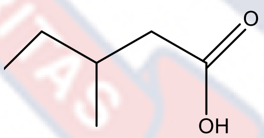


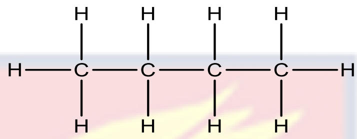
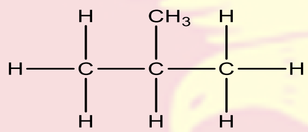
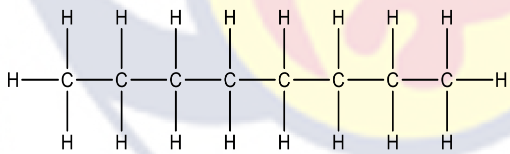
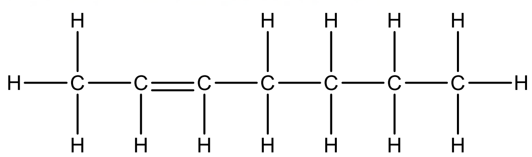
is 2-pentanol. This indicated that 14.5% of the students gave partial response and only 2.5% of the students fully understood and provided correct response. Hence, students demonstrate low level conceptual understanding IUPAC naming of secondary alcohols.

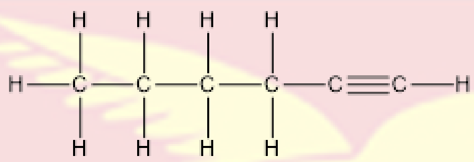
To ascertain that the bond-line formula for



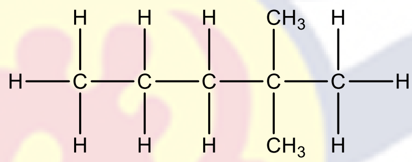
is



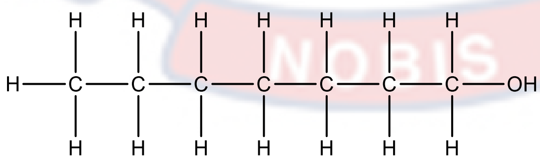
” Item 12” was used. From Table 1, the results showed that 266(96.4%) of students at a mean of .0 (Std.=.214) provided incorrect response. This indicated that 3.3% students gave partial response and only 0.4% students fully understood and gave correct response. Therefore, students exhibited low level conceptual understanding of representing structural formula of a carboxylic acid with a bond-line formula. To determine and draw open (or graphical) formula for all the structural isomers for C_4H_{10}, "Item 13" was used. The results from Table 1 showed that 227(82.2%) of the students at a mean of .2 (Std.=.430) provided incorrect response that C_4H_{10} has 2 structural isomers as , and . This indicated that 16.3% of the students gave partial response and only 1.4% of the students fully understood and provided correct response. Hence, students demonstrate low level of conceptual understanding of graphically presenting isomers of molecular formula of alkane. On "Item 17a", 124(44.9%) of the students at a mean of 1.0 (Std.=.997) provided partial response that the structural (graphical) formula for octane is . This indicated that 55.1% of the students fully understood and provided correct response. Therefore, students demonstrate moderate level of conceptual understanding of graphical (open) formula of normal alkanes. On "Item 17b", 78(28.3%) of the students at a mean of .6 (Std.=.902) provided partial response that the structural formula for 2-heptene is . This indicated that only 71.7% of the students fully understood and gave correct response. Hence, students demonstrated moderate level of conceptual understanding of writing the graphical (open) formula of unbranched-chain alkene from the IUPAC name. On "Item 17c", 216(78.3%) of the students at a mean of .4 (Std.=.826) provided incorrect response that the structural formula for hex-1-yne is



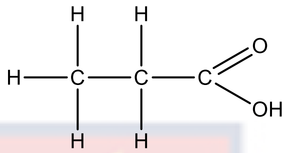
. This indicated that only 21.7% of the students fully understood and provided correct response. Hence, students demonstrated low level conceptual understanding of writing formula of unbranched-chain alkyne. On "Item 17d", 63(22.8%) of the students at a mean of .5 (Std.=.841) provided partial response that the structural formula for 2,2-dimethylpentane is



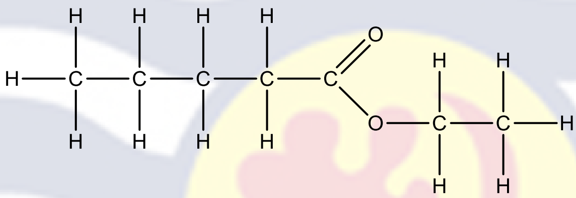
. This indicated that 77.2% of the students fully understood and gave correct response. Hence, students demonstrated moderate level of conceptual understanding of writing the structural formula of branched-chain alkane. On "Item 17e", 222(80.4%) of the students at a mean of .4 (Std.=.795) provided incorrect response that the structural formula for heptan-1-ol is



. This indicated that only 19.6% of the students fully understood and gave correct response. Hence, students demonstrated low level conceptual understanding of writing structural formula of primary alcohol from the IUPAC name. On "Item 17f", 235(85.1%) of the students at a mean of .3 (Std.=.713) provided incorrect response that the structural response of propanoic acid is



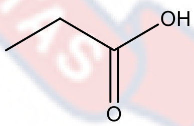
. This indicated that only 14.9% students fully understood and gave correct response. Therefore, students demonstrate low level conceptual understanding of writing structural formula of a given carboxylic acid from the IUPAC name. On "Item 17g", 263(95.3%) of the students at a mean of .1 (Std.=.424) provided correct response that the structural formula of ethyl pentanoate is

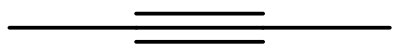
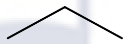
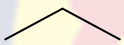


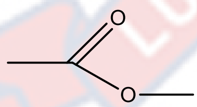
. This indicated that only 4.7% of the students fully understood and gave correct response. Hence, students demonstrated low level conceptual understanding of writing structural formula of alkyl alkanoate from its given IUPAC name. On "Item 17h", 245(88.8%) of the students at a mean of .2 (Std.=.633) provided incorrect response relating to writing structural formula of bromobenzene. This indicated that only 11.2% of the students fully understood and gave correct response. Therefore, students demonstrate low level conceptual understanding of writing structural formula of halobenzene. In general, the results indicate that majority of the students, 224(80.9%), at a mean score of .3 (Std.=.579) gave incorrect response. Hence, students exhibit low level conceptual understanding of naming and drawing structural formula of organic compounds based on IUPAC nomenclature system.

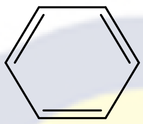
Identification of functional groups

To determine an alkene molecule amongst a group of organic compounds, “Item 1” was used. From Table 1, the results showed that 79(22.6%) of the students at a mean of 1.4 (Std.=.759) gave partial response that $CH_3CH_2CHCH_2$ is an alkene molecule. This indicated that 54.3% of the students provided correct response and 17.0% students did not fully understand and gave incorrect response. Hence, students demonstrate moderate level of conceptual understanding of identification of functional group of an alkene molecule. To identify a secondary alcohol amongst a group of organic compounds, “Item 5” was used. From Table 1, the results showed that 233(84.4%) of the students at a mean of .2 (Std.=0.447) provided incorrect response relating to the fact that $CH_3CH(OH)CH_3$ is a secondary alcohol. This indicated that 13.0% students gave partial response and only 2.5% fully understood and provided correct response. Therefore, students demonstrated low level of conceptual understanding of identifying the position of –OH functional group of a secondary alcohol. To determine that



is a carboxylic acid because of the carboxyl group, “Item 14a” was used. From table 1, 225(81.5%) of the students at a mean of .3 (Std.=.573) provided incorrect response relating to the fact that an organic compound containing the –COOH group is a carboxylic acid. This indicated that 11.6% students gave a partial response and only 6.9% fully understood and provided a correct response. Hence, students demonstrated low level of conceptual understanding that the carboxylic acids are organic compounds containing the carboxyl group. To identify the functional group of  , “Item 14b” was used. From Table 1, 204(73.9%) of the students at a mean of .3 (Std.=.628) provided incorrect response relating to the fact that the functional group of the compound is -C≡C- depicting an alkyne. This indicated that 17.8% gave partial response and only 8.3% fully understood and provided correct response. Hence, students demonstrate low level conceptual understanding in identifying -C≡C- as the functional group in alkynes. To ascertain whether the given compound  has a functional group, “Item 14c” was used. From Table 1, the results showed that 201(72.8%) of the students at a mean of .3 (Std.=.567) provided incorrect response that  has a functional group. This indicated that 22.1% of the students gave partial response and only 5.1% fully understood and provided correct response. Therefore, students exhibit low level conceptual understanding of alkanes not having any functional group that predicts their chemistry. To determine the functional group present in

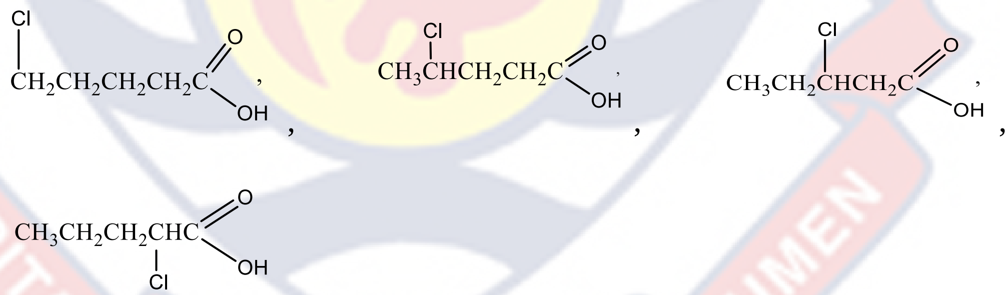
compounds of alkyl alkanoate as 

, “Item 14d” was used. From Table 1, 233(84.4%) of the students at a mean of .2 (Std.=.413) provided incorrect response that the functional group of the compound is alkyl alkanoate. This shows that 14.1% of the students gave partial response and only 1.4% students fully understood and provided correct response. Hence, students demonstrated low level of conceptual understanding of identifying the functional group of alkyl alkanoate. Also, to identify the functional group of alkene compounds, such as , "Item 14e" was used. The results showed that 204(73.9%) of the students at a mean of .3 (Std.=.600) provided incorrect response that the given compound belongs to the alkene functional group. This indicated that 19.2% students gave partial response and only 6.9% of the students fully understood and provided correct response. Hence, students demonstrated low level conceptual understanding of identifying the functional group of alkene compounds. To determine the functional group of , "Item 14f" was used. The results showed that 199(72.1%) of the students at a mean of .3 (Std.=.487) provided incorrect response that the compound belongs to the arenes functional group. Hence, students exhibit low level conceptual understanding of identifying the functional group of arenes. In general, the results in Table 1 indicate majority of the students, 188(70.0%), at a mean of .4 (Std.=.559) gave incorrect response. Hence, students demonstrated low level conceptual understanding of identification of functional groups of organic compounds.

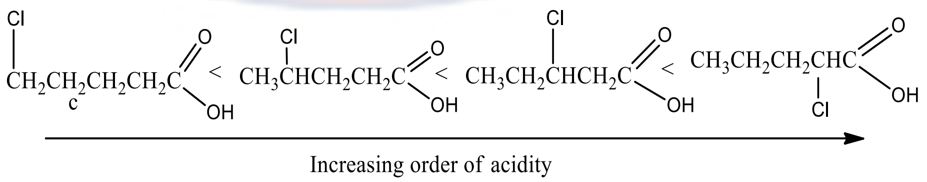
Physical and chemical properties of organic compounds

To ascertain that alcohols are organic compounds with the highest boiling point amongst a group of given organic compounds of alkanes, alkenes, and alkynes, "Item 4" was used. The results showed that 201(72.8%) of the students at a mean of .4 (Std.=.650) provided incorrect response by not selecting $CH_3CH_2CH_2CH_2CH_2OH$ as the compound with highest boiling point.

This indicated that 17.8% of the students gave partial response and only 9.45% of the students fully understood and provided a correct response. Hence, students demonstrated low level conceptual understanding of alcohols as having the highest boiling point when compared to the hydrocarbons. Also, "Item 11" was used to ascertain the compound with the highest boiling point between $CH_3(CH_2)_7CH_3$ and $CH_3(CH_2)_4CH_3$. The results showed that 60(21.7%) of the students at a mean of .5 (Std.=.705) provided partial responses that $CH_3(CH_2)_7CH_3$ has the highest boiling point. This indicated that 65.9% of the students gave incorrect response and 12.3% of the students fully understood and provided a correct response. Hence, students demonstrated moderate level conceptual understanding of determining that long chain alkanes are of high boiling point compared to those of short chain alkanes. "Item 16" was used to determine the correct arrangement of chlorine substituted alkanoic acids in order of increasing acidity.



The results showed that 261(94.6%) of the students at a mean of .1 (Std.=.338) provided an incorrect response that the right arrangement is



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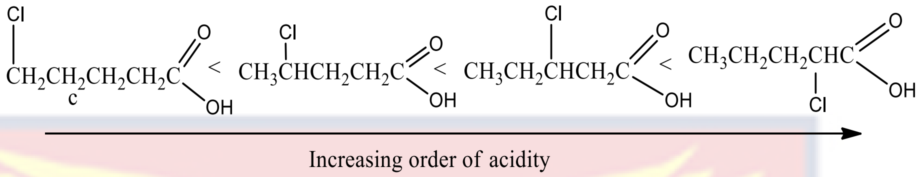
This indicated that 3.3% of the students gave partial response and only 2.2%

of the students fully understood and gave correct response. Hence, students demonstrated low level of conceptual understanding that



is the correct arrangement of the organic compounds in order of increasing acidity. In general, the results in Table 1 indicated that majority of the students 199(71.9%) at a mean score of .3 (Std.=.613) exhibited low level conceptual understanding in the physical and chemical properties of organic compounds.

The results of the study indicated that students provided incorrect responses showing students have low level conceptual understanding of all the aspects of organic chemistry covered in this study. The findings support previous studies conducted by Anim-Eduful and Adu-Gyamfi (2022); Ferguson and Bodner (2008); and corroborated by Salame et al. (2020) of students demonstrating conceptual difficulties in organic chemistry concepts. This could be attributed to the fact that students tend to have issues with the synthesis (preparation) of organic compounds due to their over-reliance on memorisation of a large number of reactions, rules, and principles governing organic synthetic reactions (Salame et al., 2020). Further, the preparation of organic chemistry requires students to use multistep transformations of one organic compound to form another, listing all required reagents and conditions (Carney, 2015; Schaller et al., 2014). This process requires not only an in-depth understanding of the structure of organic compounds and how they react to various chemical reagents, but also an understanding of how these transformations occur (that is, the reaction mechanisms) (Carney, 2015; Schaller et al., 2014). Hence, this low-level conceptual understanding of students involved in this study could that they lack control of reaction mechanism, functional groups (Anim-Eduful & Adu-Gyamfi, 2022), and even naming and drawing structural formula of organic compounds (Adu-Gyamfi et al., 2012; 2013; 2017). The complexity of synthesis problems is compounded by the fact that students must choose the appropriate reactions from the myriads of preparation methods taught throughout the teaching and learning process and apply them in the correct order to produce the desired compound (Rose et al, 2019). Consequently, students' low level conceptual understanding of synthesis of organic compounds. Students demonstrating low level of conceptual understanding of reactions of organic compounds could be attributed to their difficulties in learning and identifying functional group of organic molecules (Anim-Eduful & Adu-Gyamfi, 2022) and naming and writing structural formula of organic compounds (Adu-Gyamfi et al., 2012; 2013; 2017) making it difficult for them to reason on organic qualitative analysis (Adu-Gyamfi & Anim-Eduful, 2022). In this current study, students demonstrated low level of conceptual understanding of functional group that defines the reactivity of organic compounds.

The results from the study also show that students provided an incorrect response indicating the demonstration of low-level conceptual understanding of isomerism. That is, students have conceptual difficulties in learning isomerism. However, this phenomenon is important to students in learning IUPAC nomenclature of organic compounds and its applications and reactions of organic compounds. This weakness of students in learning isomerism could be one of the bases of their low-level conceptual understanding of IUPAC nomenclature, synthesis, and reactions of organic compounds in this study. This finding of students' low level conceptual understanding aligns with the views of Eticha and Ochonogor (2015) that isomerism is a source of conceptual difficulty for students. This could be attributed to the fact that students consider isomerism a difficult concept to understand (Nartey & Hanson, 2021). This conceptual difficulty in learning isomerism may not be new to the literature as a number of research papers have been published on it (Akkuzu & Uyulgan, 2016; Belachew, 2020; Bryan, 2007; Kyado et al., 2021; Schmidt, 1997; Sendur, 2012; Taagepera & Noori, 2000). The difficulty in recognising isomers of organic compounds is linked to the difficulties and misunderstandings surrounding organic compound representations (Rice, 2016). Students find it difficult to recognise isomers without understanding the structural representations of organic compounds. Thus, students choose compounds that are similar in shape (branched or straight) to be isomers, as students frequently limit isomeric interactions to compounds belonging to the same family (Schmidt 1997; Taagepera & Noori, 2000). Hence, students in this study demonstration of low-level conceptual understanding of reactions of organic compounds could be attributed to their difficulties in isomerism. That is, if students cannot differentiate amongst structural formula of groups of compounds of the same molecular formula, then they will find it difficult understanding the kind of reactions they undergo.

The findings indicate that students possess low level conceptual understanding about the graphic representation of organic compounds using

IUPAC nomenclature. This finding corroborates the findings of Adu-Gyamfi et al. (2012), which indicate that students encounter challenges when attempting to assign names to structural formulas of branched- and substituted-chains of alkanes and alkenes, geometrical isomers, dienes, unbranched alkynes, primary and tertiary alkanols, alkanoic acids, and alkyl alkanoates. Similarly, the findings that students have conceptual understanding difficulty drawing and naming of organic compounds such as structural formulas of carboxylic acids, unbranched and branched chains of alkanes, alkenes, and alkynes, secondary alcohols, carboxylic acid, esters, and monosubstituted benzene are supported by the results of the study conducted by O'Dwyer and Childs (2012). This could be that students were not conversant with the IUPAC nomenclature of organic compounds or teachers were not using cognitive conflicting teaching and learning approaches to confront any strong held ideas of IUPAC nomenclature that is preventing them from mastering the concept. Also, this could be that students were not exposed to more examples in these areas with varying degrees of difficulty (Adu-Gyamfi et al., 2012) or as seen in this study, the difficulties of students in isomerism are contributing to their low level conceptual understanding of IUPAC nomenclature of organic compounds. That is, scientific understanding of IUPAC nomenclature contributes to students' conceptual understanding of isomerism. Because compounds of the same molecular formula but different structural formula have different names according to the IUPAC nomenclature.

The results show that students were unable to identify and differentiate most of the functional groups provided and therefore, demonstrate low level conceptual understanding of functional groups of organic compounds. This implies that students have conceptual difficulty in learning functional groups of organic compounds (Anim-Eduful & Adu-Gyamfi, 2022) and these conceptual difficulties could be influenced the alternative conceptions students have in in learning organic chemistry. This finding aligns with the conclusion of the work of Akkuzu and Uyulgan (2016) that students have remarkable alternative conceptions and low levels of comprehension regarding certain functional group-related topics such as isomerism, aromaticity, and aliphaticity. The reported difficulties of students contributing to their low-level conceptual understanding of functional groups of organic compounds should act as a wake-up call for chemistry educators and researchers to develop effective methods to teach this concept. These difficulties have been evident during the past two decades, highlighting the need for immediate attention and novel measures to address the issue (O'Dwyer & Childs, 2011). This learning difficulties in functional groups of organic compounds could be attributed to teachers' conceptual difficulties in teaching functional groups to students Anim-Eduful & Adu-Gyamfi, 2021) as teachers are the experienced hands that support students in learning organic chemistry. Students at the introductory level of chemistry perceive all organic molecules to be the same, consisting of a molecule made up of carbons, hydrogens, and other atoms such as oxygen in the majority of situations. The most common functional groups that are included in the chemistry syllabus for SHS students in Ghana and at the introductory level are alcohols (-OH), carboxylic acids (-COOH), esters (RCOOR'), as well as aliphatic and aromatic hydrocarbons. Because each of these functional group listed here contains oxygen, carbon, and hydrogen atoms, distinguishing between them could be challenging (Hassan et al., 2004), hence, students' demonstration of low-level conceptual understanding of functional group.

Also, the results show that students have conceptual difficulty with the physical and chemical properties of organic compounds as they demonstrate low level conceptual understanding. This result confirms findings in literature by several researchers (Othmann et al., 2008; Smith & Nakhleh, 2011; Taagepera & Noori, 2000) that students demonstrate difficulty in learning properties of organic compounds. The chemical properties of organic compounds are informed by the functional group present in the molecule and in this study, students demonstrate low level conceptual understanding of functional groups. This could be the reason students have difficulties in chemical properties of organic compounds. Also, physical properties of organic compounds are related to the presence of functional group and the molecular structure, however in this study students demonstrated low level conceptual understanding of functional groups and writing structural formula of organic compounds. Hence, students in this study seem to have difficulties in all aspects of organic chemistry with one concept contributing to the difficulty in the other concept. For instance, the students in this study hold misconceptions about the factors that impact the differences in boiling points observed among homologous organic compounds. Such misconceptions could account for students' conceptual difficulties in learning physical and chemical properties of organic compounds. That is, the relationship between the molecular structure of a substance and its physical and chemical properties is a fundamental idea of chemistry and an essential ability for comprehending a subject such as organic chemistry (Rice, 2016). High school students are noted of their difficulties in forecasting the relative boiling points of organic compounds. This is attributed to students' difficulty in accurate determination of the properties of organic compounds (Schmidt, 1997).

Students' Perspectives on Barriers and Opportunities in Learning Organic Chemistry

For the second part of Research Question One, I explored the barriers and opportunities contributing to the low-level conceptual understanding (that is, conceptual difficulties) of students in learning organic chemistry. To achieve this, I interacted with students using OCSIS. The themes were barriers to learning, barriers to teaching, and preferred instructional approaches as opportunities of learning organic chemistry. The three themes emerged through the open-coding of 34 extracts from 14 students responding to the open-ended survey items, "*What are the challenges you encounter in the learning of organic chemistry*?" "*Are there any challenges in the teaching and learning of organic chemistry in the school?*" "*How do you want to be taught organic chemistry?*" The presentations are supported with some selected responses and codes (such as STD001 for student 1).

Barriers to Learning

The barriers to learning were seen as challenges in learning organic chemistry from the students' perspective. These barriers were grouped into three sub-themes after a keyword cloud mapping analysis. Thus, one barrier to understanding organic chemistry concept, another relating to inconsistent teaching methods among teachers, and other relating to few WASSCE questions on organic chemistry. There was a total of six mentions of some form of challenges relating to learning organic chemistry; 4 mentions on challenges in understanding organic chemistry concepts. For example, a student stated that

> *Some of the thing is that when you read it is very difficult to understand, for instance, when you are reading about benzene it is very difficult to understand the concepts as compared to the study of alkanes, one is able to understand it and its reactions, but for the benzenes, it gets a bit difficult. If you have a conversation with my colleagues, they would tell you they do not understand because people have been saying that is difficult*. (STD002)

Also, there was one mention related to inconsistent instructional approaches among teachers. Teachers seemed to use different instructional approaches to attract students to fee-paying extra tuition but use the conventional approach in teaching the regular classroom. For example, a student mentioned that

> *they have been learning organic chemistry only during extra classes period, and how they are taught during regular class hours are far different from how they are taught during the extra classes period.* (STD009)

Some students mentioned that they have challenges in understanding the concepts relating to organic chemistry. For example, a student said that

> *Learning organic chemistry is very tedious as the teacher is unable to complete the whole course.* (STD011)

This poses a challenge for the teaching and learning of organic chemistry. Lastly, there was one mention on the examination body (WASSCE) setting a few test items on organic chemistry compared to other areas of the SHS chemistry paper. For example, a student mentioned that

> *Going through the chemistry past questions, one will realise the examiners do not ask many questions on organic chemistry, so that makes the student think they do not need to learn it since it would not influence their performance whether they learn organic chemistry or not*. (STD003)

Barriers to Teaching

The barriers to teaching organic chemistry from students' perspective were grouped into five sub-themes after a key word cloud mapping analysis. The five sub-themes were self-tuition challenge, concept overload, pace of teaching, teacher support, and introduction of organic chemistry. There was a total of 8 mentions relating to challenges in teaching organic chemistry; two of the mentions were related to 'self-tuition'. That is, students were of the view that though they received some form of tuition from their teachers in the classroom, at the end of the day they have to learn to teach themselves. This is because they found organic chemistry to be difficult and moreover, had inadequate interactions with their teachers which could have helped to overcome their difficulties. Hence, an individual student needed to find his or her way out. For example, a student stated that

> *… So, most of the time we have to learn the concepts on our own and as I said previously due to it theoretical nature it makes it very difficult to grasp organic chemistry.* (STD006)

Again, two mentions were related to an overload of the content of organic chemistry in the SHS chemistry curriculum. Students felt there were a lot to learn when it comes to organic chemistry. For example, a student mentioned that

> *Based on my interactions with my colleagues, I gathered that organic chemistry is loaded with a lot of concepts, which make it very difficult for students to store for future and to recall, and practically impossible for the teachers to complete the scheme of work.* (STD002)

In addition, there was one mention of pace of teaching organic chemistry by some teachers as a barrier to teaching. Students' felt that teachers just rushed them through organic chemistry and this made it difficult for students to develop the scientific understanding of concepts in organic chemistry. For example, a student mentioned that

> *It is not everybody that has ability in capturing what they teach in class, as they do not take time in their lesson delivery which makes it very difficult to catch up as the concepts keeps piling up.* (STD005)

Again, there was one mention of lack of teacher support when learning by themselves. For example, a student mentioned that

> *I think how they teach is good, but most of them depend on us, like they will teach and you would have to go and revise, and in the revision, you need assistance from the teacher but you do not have it*. (STD008)

There was another mention relating to the school year or level at when organic chemistry was introduced to SHS students. For example, a student stated that

> *We do not learn organic chemistry from Form One, we are taught organic chemistry only in Form Three, even that one not all of us are taught. Only those who join extra class organised by the teacher get the opportunity to be taught organic chemistry*. (STD010)

The students therefore found it difficult or did not have the opportunity to grasp the organic chemistry concept at an early stage of their secondary school education.

Students preferred organic chemistry teaching method

Lastly, participating students were asked to respond to how they wanted to be taught organic chemistry. The responses from the students' perspective on how they want to be taught organic chemistry were grouped into five sub-themes after a cloud text mapping of keywords. The sub-themes were video assisted teaching, step-by-step presentation, explanatory methodology, organic chemistry game simulation, and practical teaching approach. There was a total of 20 mentions of a preferred method of teaching organic chemistry. Of the 20 mentions, eight were related to video assisted learning. For example, a student stated that

> *I want to feel it, like projecting lesson and examples than writing on the board. Thus, making the lesson more visual by using videos.* (STD005)

Again, six mentions were related to a step-by-step presentation of organic chemistry. For example, a student stated that

> *My teachers should take their time in teaching me and that they should present organic chemistry lesson sequentially (stepwise). To me the less difficult first and then to the next. It will make me follow and learn with ease.* (STD009)

There were four mentions relating to the explanatory teaching method, for example, a student stated that

I want more explanation on concepts in teaching organic chemistry concepts. (STD002)

Also, there was one mention of organic chemistry game simulation, for example, a student stated that

On my phone I have organic chemistry game on it, with that you are able to learn how the reactions, as you place wrong reactants in, it would not be able to react implying that the particular compound does not react with this organic compound. (STD003)

There was also one mention in favour of practical teaching of organic chemistry, for example, a student stated that

There should be more practical work, thus there should be more hands-on activities to enhance understanding of these concepts. (STD0010)

From the cloud mapping analysis of text data, it was established that the majority of students preferred video-assisted teaching method of organic chemistry as compared to the other various teaching method stated.

Teachers' Perspectives of Identifiable Barriers and Opportunities in Teaching Organic Chemistry

The responses about identifiable barriers and opportunities associated with the teaching and learning organic chemistry from teachers' perspective were grouped into four main sub-themes after a keyword cloud mapping analysis. Thus, lack of experiment materials, student attitude, poor topic introduction, and lack of opportunity. There was a total of eight mentions of some form of barriers and opportunities associated with the teaching and learning organic chemistry. There were four mentions relating to lack of experiment materials. The presentations are supported with some selected responses and codes (such as CTR001 for teacher 1). That is, all the teachers asserted lack of experiment materials as a major challenge in retrogressing teaching and learning organic chemistry. For example, a teacher stated that

> *Most of the classroom lesson delivery is done through chalk and talk (marker board illustrations). For example, when you take the identification of atoms, the elements in the organic compound, we do qualitative analysis alright, but it is just done theoretically using the marker board without any practical activity. Because most of the chemicals and equipment needed to conduct these activities are not available.* (CTR002)

There were two mentions teachers attributed to students' attitude towards organic chemistry. Because one of the identifiable barriers of teaching organic chemistry was linked to the attitude of students. That is, teachers mentioned that students did not show positive attitude towards learning organic chemistry as students felt why they should learn a concept for a whole term that they can pass the subject with good grade with or without it. For example, a teacher stated that

> *Students normally get bored as organic chemistry takes up the entire length of the term due to its huge content. As a result, fatigue set in, which affected their interest in learning organic chemistry.* (CTR005)

There was one mention which related to the poor introduction of organic chemistry concepts to students by some teachers as a barrier to teaching and learning organic chemistry. That is, teachers mentioned that students believed that at the time organic chemistry is introduced to them, the concepts therein are not familiar to them. For example, a teacher stated that

> *Another problem is how teachers introduce organic chemistry and how they make organic chemistry teaching practical and relevant for the students to appreciate these concepts. Because as the students listen to the teacher mention names of compounds such as alkanes, alkenes, and alkynes, at the end they wonder the relevance of learning about these compounds.* (CTR004)

Lastly, there was one mention of lack of opportunity. That is, teachers mentioned that there are usually no teaching and learning resources ideal for organic chemistry. Hence, a little or no opportunity was created for students to interact in the learning environment. For example, a teacher stated that

> *There are no opportunities; the only thing we have are the models, the ball and stick models that we use.* (CTR001)

Effects of Identifiable Barriers in teaching and Learning Organic Chemistry

In another development and in the attempt of answering Research Question One, the views of teachers and students on the effects of the identifiable barriers on teaching and learning organic chemistry were explored further. Teachers' perspective on these effects were also categorised into four main thematic areas after a keyword cloud mapping analysis. The themes were desire to learn, abstract learning, memorisation, and effective teaching. There was a total of seven mentions of how the identifiable barriers could affect the teaching and learning organic chemistry. Of the seven mentions, three were related to desire to learn. That is, teachers were of the view that because students have developed a negative perception that organic chemistry is difficult their moral is down towards learning organic chemistry. Thus, students show no motivation towards learning organic chemistry. For example, a teacher said that

> *When students do not like the course, no matter what you do or whatever you teach them, they will not be able to understand. Because they have the perception that I do not understand the concept and will suffer terminally from this perception.* (CTR002)

Further, two mentions were attributed to abstract teaching and learning. That is, teachers were of the view that teaching and learning organic chemistry become abstract when the material resources are not available and the most appropriate instructional strategies are not used in the processes of teaching and learning. For example, a teacher mentioned that

> *Most students want to learn through their senses by seeing and not in abstract, they should get to know exactly what we are talking about, it should not be in abstract. It affects them … at times it just becomes lecture throughout and they do not see anything. It does not give them the necessary impact as they do not get what we really want them to understand, so most often they easily forget them because their senses are not used, at times they need to touch, need to taste, need to see to aid their memory in remembering.* (CTR005)

Again, one mention was related to memorisation. That is, teachers were of the view that teaching and learning organic chemistry is ineffective when it is all about committing some concepts into memory without developing the right conceptual understanding. For example, a teacher mentioned that

In my lesson delivery I do not believe in that 'baba' thing, that is, memorisation. I believe in understanding, once the person reaches that state of comprehension it becomes easier for the students to remember whatever they have been taught. ... but because most of the organic chemistry concepts are abstract, we teach them through marker board illustrations which facilitate learning by memorisation. Mostly, the students struggle to recall concepts taught after instructions because they have adopted the principle of memorisation and they lack conceptual understanding of organic chemistry. (CTR006)

Chemistry like the other natural sciences goes with practical-based teaching and learning. The absence of practical-based teaching and learning is as a result of some of the identifiable barriers. Hence, the absence of some resources results in a lack of practical-based teaching and learning organic chemistry. For example, a teacher mentioned that

If teaching and learning materials are not there, it does not make the lesson practical as the lesson become predominantly theoretical which does not aid in students' understanding of concepts. Teaching these concepts could be easier for students to appreciate and understand if they can see what is discussed in class through practical activities. (CTR007)

Measures to reduce the effects of identified barriers

Teachers who participated in this study were asked to give their views on what should be done to limit the effects of these identifiable barriers associated with the teaching and learning organic chemistry. The teachers' perspective on what to be done to limit the effects of the identifiable barriers were categorised into four main thematic areas after key text cloud mapping analysis. These sub-themes were proportions of practical and theory lessons, concept sequencing teaching strategy, engagement of professional teachers, and teacher professional development. There was a total of 6 mentions of how the effects of the identifiable barriers associated with the teaching and learning organic chemistry could be limited. Regarding proportions of practical and theoretical lessons, teachers believed that when organic chemistry instruction is made practical in terms of laboratory activity or the use of models, it is more effective than lecture and chalk. Because more practical-based teaching and learning approaches will lessen the impact of the barriers involved with teaching and learning organic chemistry. Hence, a high proportion of teaching and learning organic chemistry should be for practical-based teaching. For example, a teacher mentioned that …

> *The teaching of organic chemistry should be activity-based, as students need to see the reactions; we need to demonstrate to them what occurs using models in the classrooms as well.* (CTR001)

Further, one mention was attributed to concept sequencing teaching, some teachers believe this could help reduce the effect of the challenges associated with the teaching and learning organic chemistry. For example, a teacher said

> *What I try to do is divide the organic chemistry into concepts, so I teach a concept, for example, on the naming and drawing of all organic compounds, before I come back to teach other concepts.* (CTR003)

Again, one mention was related to engagement of professional teachers. For example, a teacher mentioned that

> *When a teacher does not have enough education and training in organic chemistry, especially when it comes to pedagogy and mastering the subject, it affects how they teach and prepare their lessons. Some of the teachers say that they were not able to cover all the concepts that the SHS chemistry curriculum required them to prepare and teach lessons on while they were in university to be able to teach their lessons well.* (CTR005)

Lastly, there was another mention of teacher professional development. A teacher mentioned that

> *Recently, we have been attending refresher courses; we even attended one not long ago. So, when we go to these workshops, we put ourselves together, and we have developed some platforms where some of these teachers' topics are available for any member with adequate knowledge of the concepts to lead discussions on how to teach. Because there is no going back after university, continuing professional development is the way to go; these workshops serve as a platform for us to learn from one another. Also, I do encourage new teachers to get closer to the older teachers to learn from them because there are certain things you might have learned from the university but coming here to impart them is not that easy.* (CTR006)

Teachers' Current Teaching Method

The responses received from the participating teachers about *how they teach organic chemistry* were grouped into four sub-themes after a keyword cloud mapping, thus brainstorming, enquiry and demonstration, expository method, videos, and online simulation. There was a total of seven mentions of how the teachers teach organic chemistry to their students. Two of the seven mentions relate to brainstorming. For example, a teacher stated emphatically that

> *I use brainstorming to introduce them to organic chemistry because they know that we have three branches of chemistry: one is physical, another is inorganic, and one is organic.* (CTR005)

Further, two mentions were attributed to enquiry and demonstration. For example, a teacher asserted that

> *I mostly use inquiry and demonstration because when I ask them about one or two things, they do not know, so we demonstrate, but sometimes we do not do the demonstration without the chemical you sketch on the marker board.* (CTR003)

Again, two mentions were in line with exposition method, where teachers directly provide students with the information. For example, a teacher said that

> *Normally, I would say that my approach has always been the lecture method, which with time you can see is not helping. Some of the students can cope with the lecture type of delivery in class. We do these things because sometimes, the way we have been building the students, when you always want to go the practical way, let us say the demonstration approach, it is time-consuming. You want to finish the syllabus, and there are a lot of things you will want to do.* (CTR002)

Lastly, there was one mention on video and online stimulation. For example, a teacher mentioned that

> *I have a laptop and a projector here, so we look at videos and simulations online. I download them so that while I'm teaching, I can*

show them some of the practical aspects that we can't perform here because we lack the chemicals and equipment. (CTR006)

The appropriate strategy for the teaching

The teachers further expressed their opinion on what they thought should be the appropriate strategy for teaching and learning organic chemistry. The responses were grouped into two sub-themes after a keyword cloud mapping, that is practical base approach and video base approach. A total of five mentions were extracted from the text mining. Of the five mentions, four were related to the practical base approach. Thus, the majority of the teachers asserted that practical base approach is the best methodology for teaching and learning organic chemistry. For example, a teacher stated that

I believe the teaching of organic chemistry is intended to be practical in nature, with teachers demonstrating concepts to students, if not the students engaging in hands-on activities themselves. For instance, if the students are not performing it themselves, the teacher can perform the activity to demonstrate the concept. (CTR002)

Further, one mention supported the video approach as another best way to teach and learn organic chemistry. For example, the teacher mentioned that

Because the materials are not available, sometimes you can use videos. Videos could be downloaded and projected in class as you explain to students that the materials are not available so that they can appreciate what is being taught. There is this one call simulation, it can also help. (CTR007)

The text analysis of responses from teachers in teaching and learning organic chemistry showed that teachers' top most pressing challenges in teaching and learning organic chemistry was lack of experimental materials; for the effect of the challenges on in teaching and learning organic chemistry, demoralisation among students towards the teaching and learning of organic chemistry came top; for the ways to limit the impact of the challenges, teachers suggestion of more practical teaching approach than theoretical approaches was common among teachers. Further, brainstorming, inquiry and demonstration, and lecture teaching approach were the common teaching methods among teachers as compared to the video and simulation approach. Moreover, teachers think that the appropriate strategy for teaching and learning organic chemistry is the practical base approach. However, comparing the preferred teaching method that students expect, that is, the video-assisted teaching method, it is a clear indication that both students and teachers have different preferred teaching approaches. Additionally, a text similarity matrix of responses from teachers showed a similarity matrix value above *.5*, indicating that teachers shared a common perspective (See APPENDIX N). The summary of the text mapping results from teachers' perspectives on organic chemistry teaching and learning are presented in Appendix L.

The text analysis of responses from students in teaching and learning of organic chemistry shows that students' top barriers in teaching and learning organic chemistry are conceptual understanding. Additionally, when it comes to teaching and learning challenges, students identified 'self-tuition' and organic chemistry concept overload as significant barriers to teaching and learning organic chemistry. However, on the issue of preferred teaching method, most students preferred the video-assisted teaching method. This was identified after a cloud text mapping of responses from students. Additionally, a text similarity matrix of responses from students did not show a value less than .5, indicating that students shared a common perspective (See APPENDIX M). The summary of the text mapping results from students' perspectives on organic chemistry teaching and learning are presented in Appendix K.

The challenges in conceptual understanding of organic chemistry as revealed align with the conclusion of works of Adu-Gyamfi et al., (2017); Akkuzu & Uyulgan, (2016) that students have remarkable alternative conceptions and difficulty in understanding some concepts in organic chemistry. Also, students' challenges in understanding organic chemistry concepts confirms findings from the literature (Adu-Gyamfi et al., 2012; 2013; Bhattacharyya & Bodner, 2005; Childs & Sheehan, 2009; Jimoh, 2005; Johnstone, 2006; Kurbanoglu et al., 2006; O'Dwyer & Childs, 2017; Uchegbu et al., 2016) that students generally perceive organic chemistry as a problematic area of study in chemistry and face difficulties in almost all concepts in organic chemistry at the introductory level. More also, when it comes to teaching and learning challenges students see self-tuition (independent learning) and concept overload as major barriers to learning organic chemistry. The findings that students perceive self-tuition (independent learning) as a factor inhibiting teaching and learning of organic chemistry is affirmed by findings of Stoten (2014). His findings revealed that students exhibited very little inclination towards independent learning, potentially due to their resistance to change as a result of prolonged exposure of students to teacher-led instructional environment which eventually led to the observed conceptual difficulties in organic chemistry.

Further, students considered concept overload as a hindrance to effective learning of organic chemistry. This confirms that when teachers continually overload students with academic tasks and concepts, the law of diminishing returns gradually takes effect (Eduwem & Ezeonwumelu, 2020). Academic burnout, loss of motivation, and attention problems are a few of the potential repercussions of overburdening students with academic tasks and concepts they cannot realistically complete and exceed their capacity (Ogunmakin & Akomolate, 2013; Yang, 2014). Hence, students struggle to appreciate organic chemistry concepts at the introductory level (Sibomana et al., 2021). However, on the issue of preferred teaching method, most students' preferred video assisted teaching method. Somewhere somehow when videos and simulations are used in teaching organic chemistry, learning could be easier for students and scientific conceptions could be attained. It must be added that video assisted instruction has an inherent potential of changing attitudes, encouraging cognitive learning, and retaining knowledge (Tasilbeyaz et al., 2017) something which is needed in this case where students demonstrated low conceptual understanding of organic chemistry to develop scientific conception of organic chemistry to enhance learning outcomes among students (Yousef, Chatti & Schroeder, 2014).

The finding that teachers' top most pressing challenges in teaching organic chemistry is lack of experimental materials agrees with Owoeye and Yara (2011); and Hassan (2015) that lack of material resources has a negative effect on teaching and learning chemistry. This lack of teaching and learning resources results in poor content delivery by teachers and consequently, poor students' performance. There is, therefore the need to provide high schools with the needed teaching and learning resources for effective instruction where students will be actively engaged by teachers. This will lead to development of scientific conception of organic chemistry among students. The demoralisation among students in learning organic could be the result of lack of teaching and learning resources. Because whenever students are not actively interacting with resources they become passively and less motivated to learn science concepts. Hence, it is appropriate for teachers to work towards students' attitude because the formation of students' attitudes towards important aspects of science education (Lovelace & Brickman, 2013). Students with a positive attitude are more motivated to achieve academic success than those with negative attitude (Adesoji, 2008; Brandriet et al., 2011; Heng & Karpudewan, 2015; Lerman, 2014).

Practical approach to teaching organic chemistry is more effective than a theoretical approach in the perspectives of teachers for reducing the effects of the identified barriers to teaching organic chemistry. This is a good call as it will make students active and lively eliminating any low morale among students when it comes to learning chemistry. Practical instructions attained through inquiry, computer-assisted instruction, and demonstration provide students with the opportunity to engage with concepts through participatory approaches. A participatory approach helps students to develop scientific understanding and remembrance of organic chemistry concepts with ease. It is now left with teachers to select the most appropriate instructional methods in the face of inadequate teaching and learning resources but not to resort to expository teaching. Exposition could only help students to memorise without developing the scientific conception, resulting in low conceptual understanding or conceptual difficulties in organic chemistry among students. It is, therefore not surprising that students prefer computer-assisted instruction to exposition. However, due to unavailability of the needed material resources, it is prudent for teachers to find a balance between the theoretical and practical aspects of organic chemistry teaching activities to strengthen students' conceptual understanding (Wrenn & Wrenn, 2009). While a practical approach is effective in reinforcing understanding and mastery of the content, it is also important to incorporate computer-assisted teaching methods to keep students engaged and motivated. For instance, video viewing is a unique and effective educational tool as reported elsewhere (Gaudin & Chaliès, 2015) and can be adapted to teach organic chemistry to high school students in Ghana. Incorporating videos into educational practices enables students to surpass the constraints of the physical world and discover the potential of digital environments in enhancing their understanding of organic chemistry concepts (Giannakos et al., 2016).

Alternative Instructional Strategy for Teaching and Learning Organic Chemistry

Research Question Two sought to explore an alternative means of teaching and learning organic chemistry to improve students’ conceptual understanding of organic chemistry.

To address Research Question Two, an instructional design was drafted by the researcher and was validated by experts in science education and instructional design. Two teaching try-outs were conducted to improve the draft intervention which led to a final instructional plan that was implemented to improve teaching and learning organic chemistry in the SHS classrooms in Ghana. The findings from the OCCUS-1 from the preliminary phase revealed that SHS students have low-level conceptual understanding in all concepts in organic chemistry, Furthermore, findings from the interview schedule (OCSIS and OCTIS) revealed that students prefer to be taught organic chemistry using computer-assisted instruction (video assistance and simulations), step-by-step presentation, and a practical teaching approach. In addition, the most effective method of instruction, according to the teachers, was the use of the videos and practical instruction. Furthermore, views from chemistry educators were factored into the alternative instructional design. The theory-based organic chemistry instructional plan (TB-OCIP) was developed on the integration of insights from chemistry teachers, students, and subject matter experts, as well as a comprehensive evaluation of the current literature. This plan, based on the aforementioned inputs and the literature review, was developed to support the development of an effective instructional strategy tailored to the teaching of organic chemistry. Some interventions were considered as design guidelines that governed the development of the TB-OCIP. These interventions

a) Were guided by the Gagne Nine instructional sequence framework to develop an effective lesson sequence (Gagne & Brigges 1974).
b) Integrate videos, simulations, and animation to promote a participatory and active classroom (Akcayr & Akcayr, 2018).
c) Take into consideration a situated learning approach to learning for the enforcement of teamwork capabilities in students (Lave & Wenger, 1991).

d) Take into account formative assessment strategies to improve students' learning outcomes (Bennett, 2011; Van der Kleij et al., 2015).

The aforementioned design principles for the study guided the creation of the TB-OCIP design. The TB-OCIP design had the following characteristics: 1) Gagne-Nine instructional sequence; 2) situated learning approach; 3) formative assessment; 4) video-based learning. Figures 5 and 6 present the various theories and model that constituted the TB-OCIP.

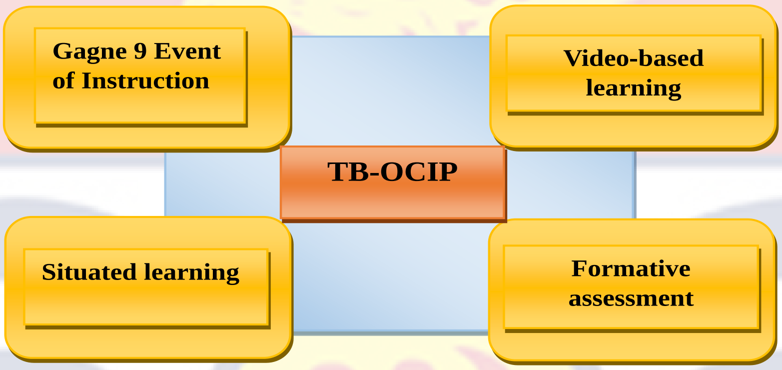


Figure 5: TB-OCIP design (Gyang, 2023)

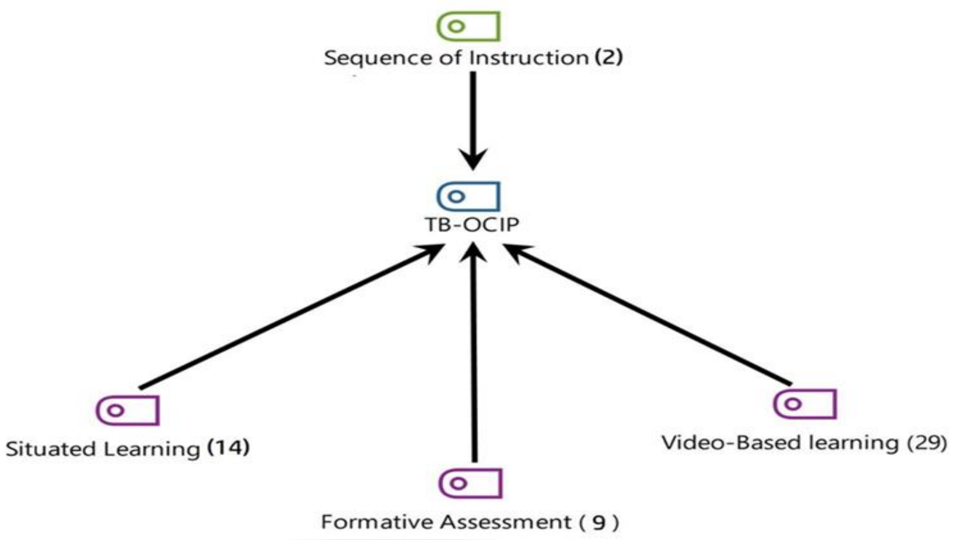


Figure 6: Model of the Theory-Based Organic chemistry Instructional Plan (TB-OCIP) (Gyang, 2023)

The Gagne Nine Events of Instruction offered the teacher the opportunity to deliver the lesson sequentially. Chemistry educators proposed that the third stage of the Gagne Nine Events of Instruction should be placed as the second stage in the sequence. This adjustment aims to ensure a seamless flow of lesson delivery that aligns with the natural order. The suggestion made by the chemistry educators reflects Gagne' views that these nine events could be applied to any form of instructional activity and learning, regardless of their application or order. It is possible to modify the use of these events based on the teacher, students, objectives, and instructional materials: "The events relate to the learning of all sorts of learning outcomes. The arrangement of these events throughout a lesson or lesson segment is approximate and may vary slightly based on the purpose. Not all of them are always employed. Some are caused by the instructor, others by the student, and yet others by the teaching materials" (Gagne' & Brigges, 1974, p. 135). In this study, the teacher and students carefully navigated through the lesson stepwise, ensuring optimum conceptual understanding. The instructional strategy took into account external factors, such as the learning environment, resources, and management of learning activities, which interact with internal conditions, such as the learner's attitude toward the learning task, prior knowledge, and individual learning goals, to develop the anticipated learning outcomes (Driscoll, 2000). Further, these steps provided an avenue for the teacher to employ instructional strategies and learning resources to attract the students' attention and prepare them adequately to develop conceptual understanding (Mei, Ramli & Al Hertani, 2015). Figure 7 presents the instructional sequenced used to design the TB-OCIP.

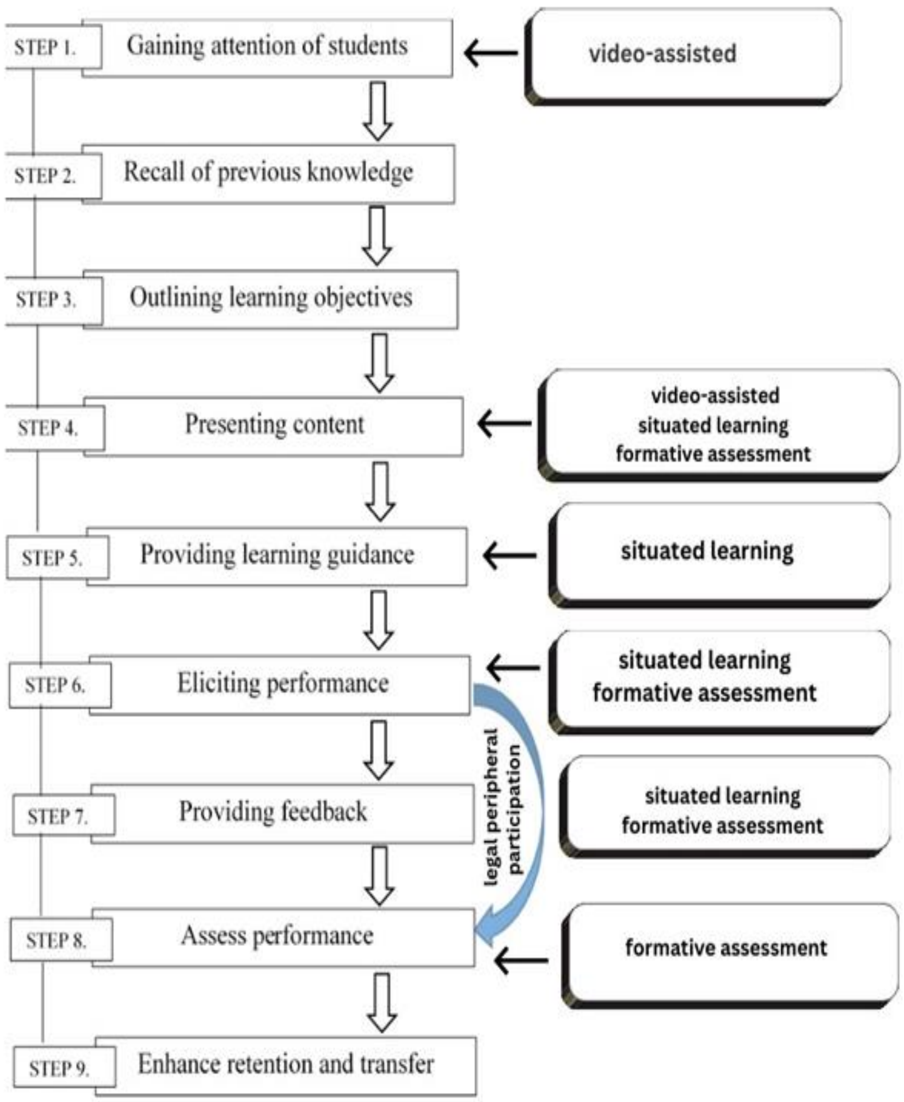


Figure 7: Final TB-OCIP delivery procedure (Gyang, 2023)

The situated learning approach enabled the students to learn collaboratively (Lave & Wenger, 1991) in a natural environment where they were able to interact with one another through the sharing of ideas and perspectives (Herrera & Riggs, 2013). This ensured that students actively participated (Streule & Craig, 2016) and were well integrated into the class activities (Waldron, Locock & Pujadas-Botey, 2016). This further ensured that students learned from their interactions with the other members of their group (Fenwick, 2001) and had the opportunity to grow intellectually (Mills, 2013).

The teacher used the formative assessment technique throughout the lesson to generate student feedback and assess their progress on the lesson. The feedback helped the teacher steered learning (Poortman & Schildkamp, 2016) and influenced students' learning processes (van Geel, Keuning, Visscher & Fox, 2016) to improve their learning outcomes through the provision of immediate feedback on students' responses (Vermeulen, Schildkamp & Eggen, 2015).

Video-based learning enabled the teacher to attract the attention of the students (Giannakos et al., 2016) through the presentation of videos, animations, or simulations on the concepts to be taught. This allowed the teacher to observe the class as students solved problems through group sharing of ideas (Akcayr & Akcayr, 2018) and explained how they arrived at solutions to the given problem. Further, the teacher and the students were able to overcome the practical limitations of abstract concepts (DeLozier & Rhodes 2017).

Effectiveness of TB-OCIP in Improving Students' Performance in Organic Chemistry

The first part of Research Question Three examined the effectiveness of the instructional strategy in improving students' performance in organic chemistry. This was accomplished by comparing students' pre-test and post-test scores. Figure 8 displays the percentage of students who scored each item correctly on the pre-test and post-test.

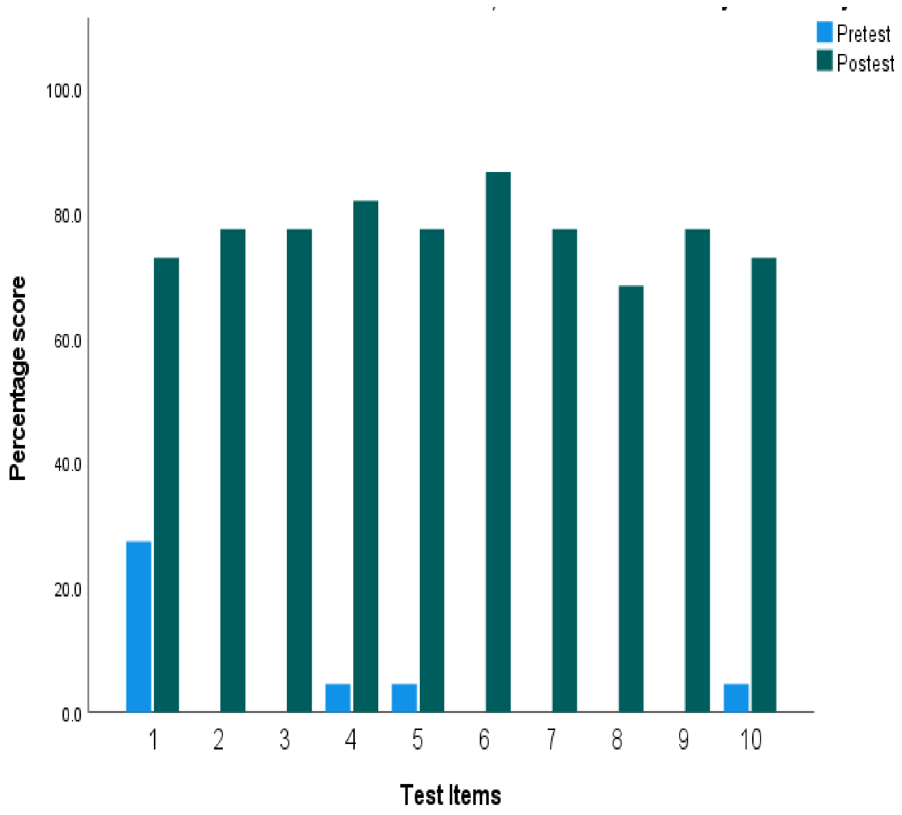


Figure 8: Percentage score in pre-test and post-test on organic chemistry.

Figure 8 shows that students failed to provide the correct response for all pre-test questions on organic chemistry except in four items. For instance, Item 1 had a high percentage (27.3%) of the students prior to the intervention gave correct responses in the pre-test and the remaining items received fewer than 5% correct responses from the students compared to the number of students who gave correct responses in the post-test after the intervention. Therefore, the students, in the pre-intervention stage had difficulty with their conceptual understanding of organic chemistry. The results of the pre-test corroborated the findings of the preliminary phase, in which the students exhibited similarly low level conceptual understanding of organic chemistry. In the post-test, however, the vast majority of students correctly answered the majority of questions on organic chemistry. In some instances, 86.4% of the students provided correct responses. The lowest percentage of students who gave correct responses to one of the post-test items was 68.2%. This indicates that teaching and learning organic chemistry with TB-OCIP helped students better to internalise the concepts, resulting in an increase in the number of students who correctly answered the post-test.

Table 2 shows the results of the mean score of students' performances in the pre-test and the post-test. The mean scores obtained involving reactions; isomerism; naming and drawing; identification of functional groups; physical and chemical properties of organic compounds are 1.6 (Std. =.6); 1.7 (Std. =.0); 1.8 (Std. =.4); 1.9 (Std.=.4); and 1.8 (Std. =.3) respectively, with a minimum score of 0.5 mark and a maximum score of 2.0 marks out of a total score of 2.0 marks. The students correct response mean scores vary between 1.6 and 1.9 out of a possible 2.0 marks. The results clearly revealed that students' performance in organic chemistry concepts has significantly improved. This could be attributable to the students' improved conceptual understanding of organic chemistry as a result of their TB-OCIP learning experiences.

Table 2: Students' Mean Scores in the Pre-test and Post-test

			Pre-test				Post-test			
Organic chemistry concepts	N	No of Items	Mean	Std.	Min	Max	Mean	Std.	Min	Max
Reactions of organic compounds	22	2	.4	.3	.0	1.0	1.6	.6	.5	2.0
Isomerism in organic compounds	22	2	.4	.4	.0	1.5	1.7	.3	1.0	2.0
Naming and drawing of organic compounds	22	2	.4	.4	.0	1.0	1.8	.4	1.0	2.0
Identification of functional groups	22	2	.5	.5	.0	1.0	1.9	.4	1.0	2.0
Physical and chemical properties of organic compounds	22	2	.3	.3	.0	1.0	1.8	.3	1.0	2.0

Source: Field data (Gyang, 2023)

The results from the Wilcoxon signed rank test in Table 3 revealed that students' performance in organic chemistry improved after the intervention (TB-OCIP). Students' performance in the post-test improved compared to their performance in the pre-test. That is, post=test (*Md*=1.70, *n*=22) compared to pre-test (*Md*=0.45, *n*=22) *z*=-4.112, *p*=.001 with a large effect size, *r*=0.88. Hence, students' performance significantly improved in learning organic chemistry in the TB-OCIP lessons.

Table 3: Wilcoxon Signed Rank Test Results for Student's Performance on Organic chemistry

	Pre-test		Post-test				
	N	Md.	N	Md.	Z	P	r
Performance in Organic chemistry	22	.45	22	1.70	-4.112	.001*	.88

* Significant, $p < 0.05$
Source: Field data (Gyang, 2023)

The findings from the results of the pre-test and post-test comparison of the performance of students on organic chemistry show that there is significant difference between the pre-test scores and post-test scores on the students' performance in organic chemistry. That is, students' performance of organic chemistry improved after the implementation of the TB-OCIP in the teaching and learning process. These significant increases with a large effect size in the performance of students on organic chemistry are considered to be due to the encouragement of active classroom participation in a naturalistic environment (Bricker & Bell, 2014; Sawyer, 2014), where students were engaged in active sharing of ideas. The instructional strategy was designed to facilitate the sharing of ideas, which allowed students to clarify their own understanding of organic chemistry concepts by explaining them to others and by hearing alternative perspectives from their colleagues in the group (Tombak & Altun, 2016). Furthermore, the effective sharing of ideas in community practice might have improved students' conceptual understanding of organic chemistry through diverse perspectives and explanations (Streule & Craig, 2016). When students are members of a group in which they are immersed and actively participating, conceptual understanding occurs (Fenwick, 2001; Lave & Wenger, 1991). This lends support to the positive effect of the TB-OCIP-based lesson on students' improved performance of organic chemistry as measured by the post test.

Improvement of students' Conceptual Understanding of organic Chemistry

The second part of Research Question Three examined the improvement observed in students' conceptual understanding of organic chemistry. To help students improve their conceptual understanding of organic chemistry, five lessons were conducted to cover the same key concepts under organic chemistry: reactions, naming, and drawing, identification of functional groups, and physical and chemical properties of organic compounds. These lessons were executed using TB-OCIP with the sole aim of developing conceptual understanding of students in organic chemistry. The following is a presentation of results from students' conceptual understanding of the aforementioned concepts. The presentations are supported with some selected responses and codes (such as SPT001 for students 1 in the pre-test and SPOT001 for students 1 in the post-test).

Reactions of organic compounds

To determine students' conceptual understanding of reactions of compounds, the same Items, 3 and 7 were used in the pre-test and post-test. The results are grouped as follows:

Incorrect response: for Item 3, student (SPT012) gave the incorrect response that halogenation is the method used to convert vegetable oil to margarine as,

"vegetable oil is acidic" (SPT012).

However, in the post-test, student (SPOT012) provided a correct response that hydrogenation is the reaction between an alkene molecule and hydrogen in the presence of a catalyst (Pd) as

"Hydrogenation is the process of adding hydrogen to unsaturated hydrocarbons to form an alkane in the presence of a catalyst (SPOT012).

Incorrect response: For Item 7, student (SPT013) selected the incorrect response that oxidation is the common reaction of alkynes with hydrogen gas in the presence of palladium to form an alkane and failed to provide a reason for the response.

However, in the post-test, student (SPOT013) selected the correct response that alkenes are more reactive than alkynes as,

"Alkynes are usually less reactive than alkenes in electrophilic addition reactions because the pi electrons are tightly held in the C≡C bonds than in C=C bonds." (SPOT013)

Isomerism of organic compounds

To determine students' understanding of isomerism in organic compounds, the same Items, 5 and 8 were used in the pre-test and post-test. The results are grouped as follows:

Incorrect response: for Item 5, student (SPT021) selected the incorrect response that cis-trans isomerism is possible in 1,1-dibromoethene and failed to provide reasons.

However, in the post-test, student (SPOT021) selected the correct response that cis-trans isomerism is possible in 1, 2-dichloroethene as,

"*The carbon atoms bearing the double are bonded to two different atoms*." (SPOT021)

Incorrect response: For Item 8, student (SPT003) selected the incorrect response that alkynes show cis-trans isomerism in their molecules as, *"Alkynes exhibit cis-trans isomerism in their bond because the hydrogen attached to each carbon are found on the same side."* (SPT003)

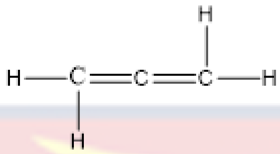
However, in the post-test, student (SPOT003) selected the correct response that alkynes do not show cis-trans isomerism in their molecules as,

"Each carbon-carbon triple bond is bonded to single hydrogen atom." (SPOT003)

Naming and drawing of organic compounds

To determine students' conceptual understanding of naming and drawing of organic compounds, the same Items, 1 and 10 were used in the pre-test and post-test. The results are grouped as follows:

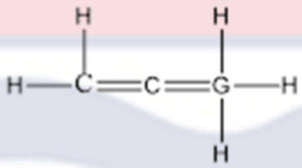
Incorrect response: for Item 1, student (SPT005) selected the incorrect response that the structural (graphical) formula of this molecule



is incorrect as,

"It is no arranged properly." (SPT005)

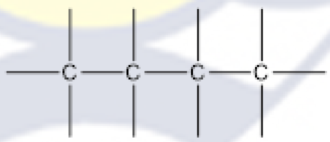
However, in the post-test, student (SPOT005) selected the correct response that the structural (graphical) formula for this molecule



is incorrect as,

"*The number of bonds around the third carbon is five instead of four*." (SPOT005)

Incorrect response: For Item 10, student (SPT006) provided an incorrect response by drawing the structural (graphical) formula for 1-chloro-2,2-dimethylpentane as



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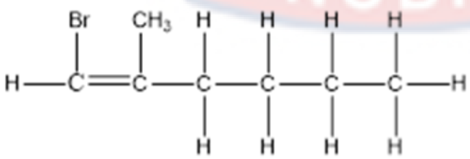
However, in the post-test, student (SPOT006) was able to draw the structural (graphical) formula for 1-bromo-2-methylhex-1-ene as



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Identification of functional groups in organic compounds

To determine students' conceptual understanding of identifying functional groups of organic compounds, the same Items 4 and 6 were used in the pre-test and post-test. The results are grouped as follows:

Incorrect response: for Item 4, student (SPT001) selected the incorrect response that the functional group in the molecule $H_2C{=}CH_2$ is a carboxyl as

"*Because carbon atoms are bonded.*" (SPT001)

However, in the post-test, student (SPOT001) selected the correct response that the functional group in the molecule $HC{\equiv}CH$ is a triple bond as,

"This is because it is an alkyne and therefore have triple bonds between the carbon atoms." (SPOT001)

Partial response: for Item 6, student (SPT018) selected the correct response that the carbon-carbon triple bond of an alkyne is composed of 2-sigma bonds and 1 pi bond, but failed to provide reasons for the selected response.

However, in the post-test, student (SPOT018) selected the correct response that the carbon-carbon double bond of an alkene is composed of 1 sigma bond and 1 pi bond as,

"This is because the carbon-carbon double in an alkene exhibit sp^2 hybridisation making it possible for a lateral bond (pi bond) and head-on bond (sigma bond) to form." (SPOT018)

Physical and chemical properties of organic compounds

To determine students' conceptual understanding of physical and chemical properties of organic compounds, the same Items, 2 and 9 were used in the pre-test and post-test. The results are grouped as:

Incorrect response: for Item 2 student (SPT0011) selected the incorrect response that alkanes are soluble in water and failed to provide reasons for the selected response.

However, in the post-test, student (SPOT0011) selected the correct response that alkanes have a higher boiling point than alkenes as,

> *"Alkene molecules have two less electrons than an alkane of the same number of carbons, its dispersion force is slightly weaker. Therefore, making the boiling point of alkenes lower than those of alkanes."* (SPOT0011)

For Item 9, student (SPT017) selected the incorrect response that alkynes are more reactive than alkenes as,

> *"Alkenes are generally unreactive."* (SPT017)

However, in the post-test, student (SPOT017) selected the correct response that alkenes are more reactive than alkynes as,

"Alkynes are usually less reactive than alkenes in electrophilic addition reactions because the pi electrons are tightly held in the C≡C bonds than in C=C bonds." (SPOT017)

The findings suggest that students' conceptual understanding of organic chemistry improved in the post-test. This improvement can be attributed to the activation and enhancement of learners' relevant cognitive processes through video-watching, formative assessment, and community of practice (Merrill, 2002). The video-watching catered for the diverse learning styles of the students by presenting organic chemistry concepts in multiple modes (Brualdi, 1996; Mayer, 2001; Yousef et al., 2014). Moreover, the implementation of an effective instructional method that takes into account students' preferred learning mode has an overarching effect on the conceptual understanding growth of students (Arthurs, 2007; Rogers, 2009), as learners actively engage in the learning process to facilitate deeper learning of organic chemistry (Dede, 2014). This has the capacity to ensure effective retention, intrinsic motivations, lasting knowledge, and a systematic understanding of the fundamental concepts and procedures of organic chemistry (Dede, Grotzer, Kamarainen & Metcalf, 2017). Additionally, students' conceptions were stimulated through self- and peer-assessment as well as feedback on their learning (Elwood & Klenowski, 2002). It has been mentioned that the quality and accuracy of feedback are essential to the learning process because they allow students to personalize their learning (Timmis et al., 2016). This is essential for enhancing students' conceptual and procedural performance in organic chemistry (Hagos & Andargie, 2017). Furthermore, the sharing of ideas and interactions among students in groups provided opportunities for students to develop problem-solving skills and foster personal acquisition of knowledge in organic chemistry (Lave & Wenger, 1991; Mills, 2013). These suggest that the use of TB-OCIP was effective in the teaching and learning of organic chemistry.

Students' Perception on the TB-OCIP Intervention

The first part of Research Question Four examined students' perceptions of the use of TB-OCIP in teaching and learning organic chemistry.

To address Research Question 4, students completed the OCIPS, an 18-item questionnaire that examined their thoughts of the TB-OCIP immediately following five TB-OCIP-based lessons during the implementation and assessment phase of the DBR approach. The mean scores of students in the OCIPS for each of the subscales are indicated in Table 5. On a five-point Likert scale, responses to the questionnaire were evaluated as follows: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. The mean values between 1.0 to 2.4; 2.5 to 3.4; 3.5 to 5.0 indicate negative perception, neutral perception, and positive perception of the instructional strategy respectively. Based on the students' thoughts and experiences with TB-OCIP lessons, the items were categorised into four themes: 1) Active: this was intended to measure the students' level of engagement and active participation; 2) Delivery: this was used to determine if the concepts were delivered sequentially and adequately explained; 3) Understanding: this was intended to examine the lesson's clarity and student comprehension; 4) Motivation: this was used to establish whether the lessons captured and maintained the students' attention. The majority of students in the study indicated a positive perception of the use of TB-OCIP in teaching organic chemistry at a mean of 4.3(Std.=.314). That is, participatory, 39(94.7%) students at a mean of 4.48 (Std.=.302), delivery, 38(92.7%) of the students at a mean of 4.40(Std.=.353), understanding, 39(92.7%) students at a mean of 4.46(Std.=.778), and motivation, 37(89.3%) of the students at a mean of 4.34(Std.=.656) gave positive perceptions on the use of TB-OCIP in teaching and learning organic chemistry.

Table 4: Levels of Students Perception on TB-OCIP (N=41)

	Level of perception								
Themes	Agree N	%	Neutral n	%	Disagree N	%	N	Mean	Std.
Participatory	39	94.7	1	3.6	1	1.7	41	4.48	.302
Motivation	39	97.6	2	2.4	0	0.0	41	4.59	.357
Delivery	38	92.7	2	6.1	1	1.2	41	4.40	.353
Understanding	31	75.7	8	19.5	2	4.9	41	3.88	927

Source: Field data (Gyang, 2023)

The results obtained from the first part of Research Question 4 indicate that students' levels of engagement, attention, lesson delivery, and comprehension was positively perceived. These factors are known to predict students' academic improvement and learning outcomes (Hong-sheng, 2005; McAuley, Leskovec & Jurafsky, 2012; Tandogan & Orhan, 2007), and they also enhance their commitment to the teaching and learning of organic chemistry (Oh & Yager, 2004). The positive perceptions of the students suggest that the TB-OCIP-based intervention could result in an enhanced conceptual understanding of organic chemistry.

Students' Experience with the TB-OCIP Intervention

The second part of Research question Four sought to determine students' experiences with the instructional strategy in the lesson delivery.

The results from student interviews conducted during the teaching try-out at the implementation and assessment phase of the study are reported here. I engaged students to gain insight into their experience on the use of TB-OCIP in teaching and learning organic chemistry to refine the instructional design in an iterative cycle. To achieve this, I interacted with students using OCIIS, and themes were extracted to represent the results. The presentations are supported with some selected responses and codes (such as SGPI-1-001 for student 1 in group interview 1 and SGPI-2-001 for student 1 in group interview 2).

The students were asked to share their views on the organic chemistry lesson based on the intervention implemented. That is, students were to share their views on whether learning chemistry through TB-OCIP was successful. The students asserted that the lessons were successful. Three mentions were counted for the success of TB-OCIP lessons. For instance, students expressed that TB-OCIP lesson was very interesting based on their perceived difficulties in organic chemistry that they had overcome. A student in group one stated that

> *This lesson was a very interesting one. At first, I found organic chemistry to be a very difficult topic, but at the end of the lesson, I got to understand it.* (SGPI-1-009)

There was a mention of the kind of assessment practices used in the TB-OCIP lesson on the basis of students mentioning that the lessons were successful. A student in group two mentioned that:

> *I think the work example you gave us during the lesson has really helped us understand the lesson.* (SGPI-2-004)

Again, there was a mention of 'practical visualisation' as a contributing factor to the success of the TB-OCIP lesson. For example, a student in group one stated that:

> *It was successful because we were mostly taught by someone showing us or writing it on a blackboard, but today we have watched it in video form, and it has improved our thinking skills and we have understood it well.* (SGPI-1-015)

Effectiveness of the instructional activities

Students were asked to express their opinion on the relevancy of the instructional activities and the media used for the delivery of the organic chemistry lesson. There were four mentions about the relevancy of the instructional activities and the media used. Students asserted that the instructional activities and the media were relevant because they led to effective concept development. For example, a student in group one stated that:

Yes, it explained much detail. (SGPI-1-006)

There was a mention that the concept was well explained. For example, a student in group one mentioned that:

It explains the topic and concept well. (SGPI-1-011)

Others also attributed the relevancy to the visualisation of organic chemistry structures and the absence of teacher-centred delivery. For example, a student in group one stated that

Most of the time we are taught theory, but today we have it in video and how to write the structures and formulas of the carbons on the projector, so it is good. (SGPI-2-012)

The interactivity of the instructional strategy

Students were tasked with expressing their view on how the instructional activities and the media used helped in the interaction among their group and colleagues during the delivery of the organic chemistry lesson. There were four mentions about how the instructional activities and the media used helped in the interaction among their group and colleagues. The student emphasized that the activities and the media were interactive and helped to figure out solutions to questions. For example, a student in group two stated that:

> *Yes, it helped me find solutions to questions, and I also understood it very well because of the sharing of ideas*. (SGPI-2-016)

There was a mention of enhanced conceptual understanding. For example, a student in group one mentioned that

> *Maybe you get stuck at a place that you do not understand, but the sharing of ideas will help you to understand very much.* (SGPI-1-004)

Other students also mentioned improved collaboration. For example, a student in group one argued that:

> *Working in groups helped us to improve our class bonding skills and our relationship with the class.* (SGPI-1-010)

There was a mention of enhanced sharing of solutions to a problem. For example, a student in group two stated that:

> *Because it is in video form and all of us were watching the video together, we just witnessed it together, so each of us saw how it went about, so if there is any interaction or any misunderstanding through the video we watched and all of us watched it, we can discuss it, and when we don't understand, even when your friend can, you can ask that person to interact with you to know how it went about.* (SGPI-2-010)

Identified challenges in the instructional strategy

Students shared the challenges they encountered with the instructional activities and the media used to deliver the organic chemistry lesson. There were six mentions of some challenges encountered by students during the lesson delivery. These challenges include difficulties with video and PowerPoint graphics. For example, a student in group one with support from other group members stated that:

> *I have a challenge with the graphics in the video. Some of us did not see the videos clearly since they were not magnified.* (SGPI-1-001)

There was a mention of a challenging accent in the video. For example, a student in group two mentioned that:

> *The accent was different, so I really did not understand it.* (SGPI-2-003)

A student in group one with similar sentiment shared by other group members stated that the challenge has to do with the fast pace of the video. For example, the student stated that:

> *Since most of us have not been introduced to this kind of topic, we find it difficult because the introduction of the concept in the video was fast, so we were not able to catch up.* (SGPI-1-007)

Suggestions for improvement of the instructional strategy

Students expressed their views on the area of the lesson delivery that need to be strengthened. There were two mentions of areas that needed to be strengthened. Students mentioned enhanced collaborative activities. For example, a student in group one stated that:

> *The trial work … I mean, the group work … was good.* (SGPI-2-003)

Again, there was a mention of extended formative assessment. For example, a student in group one mentioned that:

> *We need more and more trial work in the lessons.* (SGPI-1004)

Students who took part in the organic chemistry lesson were tasked to further suggest areas in the lesson that needed improvement to enhance future lesson delivery. There were five mentions relating to areas that need improvement. There were mentions relating to the augmentation of video graphics. For example, a student in group two stated that

> *The visuals should be improved, by which I mean the PowerPoint projection and video.* (SGPI-2-009)

Some suggested altering the accent in the video. For example, a student in group one stated that:

> *The accent should be changed.* (SGPI-1-007)

Again, another student suggested a prelude to the video. For example, a student in group two stated that:

> *Sometimes pause the speaker and explain a bit before you continue since everyone is complaining the speaker is speaking too fast, so we can pause and you, the teacher, explain a bit.* (SGPI-2-010)

Modifications of the initial designs

From the model counts, response map-network, and keyword code mapping, it was revealed that students shared concern about the graphics of the instructional activities and videos used in the class delivery, the fast pace of the video. Further, the students' suggested that the graphics of the video used in the lesson should be augmented, as well as ensuring that videos have a prelude before and during display. The opinions and suggestions were considered and factored into the review of the instructional strategy for implementation. For instance, videos on organic chemistry concepts to be taught were carefully selected based on established criteria for selecting educational videos for teaching and learning, suitability with respect to the narrator's English accent and content, accessibility, interactivity, organisation, and speed (Khoiriyah, 2020). An instructional video that has good graphics with good narration, speed, and organisation is able to improve both learning outcomes and learner satisfaction (Beheshti, Taspolat, Kaya & Sapanca, 2018). Further, adequate measures were taken to focus much attention on providing video visuals on organic compounds to offset students' challenges. I, also, ensured that a brief introduction was provided at the beginning and during the display of each video to contextualise and shape students' expectations. Moreover, the students expressed their views affirming the success of the lesson with the use of the intervention. The students intimated that the uniqueness of the instructional strategy as compared to what they are used to during chemistry lessons was able to eliminate difficulties they have had with conceptualisation of chemistry concepts. This could be attributed to the interactive nature of the instructional strategy where students extensively exchanged ideas in groups after watching videos on organic chemistry concepts and applying same in solving work examples during the teaching and learning process which enable the teacher the monitor progress of students' learning development.

Students' perspectives on interesting aspects/parts of the TB-OCIP based lesson delivery

The third part of Research Question four sought to determine aspects/parts of the instructional strategy in the lesson delivery that students considered interesting. The presentations are supported with some selected responses and codes (such as Student, 021 for student 21).

Students were asked to evaluate the lesson delivery activities by submitting an exit card. Students were asked to express and explain the most interesting thing/part/aspect of the organic chemistry lesson delivery. The analysis of the responses from the students shows some mentions of interesting things/part or aspect of the organic chemistry lesson delivery that were captured under the following themes as illustrated in Table 6: video-based learning, formative assessment, situated learning, sequence of instruction.

The results obtained from the student exit cards indicated that the video utilized in the session was identified as the most captivating component of the intervention 29(53.7%). Furthermore, it is important to acknowledge that 9(16.6%) of the responses, characterised the class work as the most captivating aspect of the instructional process. Additionally, 14(25.9%) of the participants, expressed that the aspect of the lesson that captivated their attention the most was the chance to engage in collaborative group work. This allowed them to exchange ideas pertaining to the video lesson's content and collectively solve problems. Also, 2 (3.8%) of the students mentioned the sequence of the lesson as the most interesting aspect.

Table 5: Response categories of the Exit card

Themes	N	(%)
Video-based learning	29	53.7
Formative assessment	9	16.6
Situated learning	14	25.9
Sequence of instruction	2	3.8

Source: Field data (Gyang, 2023)

Video-based learning

From the results, majority of the students 29(53.7%) mentioned video-based learning as the most interesting part of the lesson. The TB-OCIP was purposed to integrate video-based learning into the teaching and learning process. Students were required to watch brief videos at step 1 of the instructional strategy. This strategy was employed to achieve multiple goals, including engaging and sustaining students' interest in the class and enhancing students' participation during the learning experience (Sloan & Lewis, 2014). The students' participation, interest, and attention were enhanced, which encouraged them to retain and develop conceptual understanding of the concepts to be taught (Driscoll, 2000). The students' attention in the teaching and learning transaction is very important ingredient for effective learning (Slavin, 2009). This is because for effective learning to take place, students focus on the incoming instructional activities must be activated by shifting their priorities through the use of videos (Gagne, et al, 2005; Tofade, Elsner & Haines, 2013). For example, there was a mention that the video viewed at the beginning of the lesson adequately prepared their minds for the lesson, and a student remarked that:

> *I focused on the lesson because the video brought my attention to the room and really participated on the lesson from beginning to the end.* (Student, 002)

Another student remarked that:

> *At the beginning of the lesson, I was feeling very tired and sleepy so watching the ice breaker videos made me more active and ready for the lesson.* (Student, 011)

There was also a mention of the video viewing helping to explain and promote understanding of organic chemistry concepts at Step 3 of the instruction, and a student remarked that:

The videos made us understood the concepts of organic chemistry. Most students see this topic to be complex one but because videos were shown in it made the lesson very interesting and understandable. (Student, 001)

Another student remarked that:

It was interesting for me because the videos promote more understanding than teaching without them. (Student, 003)

There was a further mention of the novelty of the video viewing in the lesson as it presented a new experience in the teaching and learning of organic chemistry, and a student remarked that:

The video part made us to concentrate since it was not an ordinary way we learn in our school. We were entertained and educated at the same time. (Student, 005)

Another student remarked that:

Since we are always taught with textbooks, using video interaction serve us a new experience for us, so we captured what we saw quickly to make learning easier. (Student, 010)

There was also a mention of the video simulations providing visualization of organic molecules, and a student remarked that:

I have always been taught using marker for drawing on the board and also writing so this strategy the teacher used to teach us made me fall for the lesson, leading to easy understanding of the lesson. (Student, 013)

Another student remarked:

The drawing of the structures was interesting because it was observed through the videos. (Student, 015)

Furthermore, there was a mention that the video viewing attracted their attention and participation, and a students remarked that:

The videos made us active during the lesson since we had to pay attention and make some notes on our own. Also, it made the lesson under organic chemistry very understandable. (Student, 008)

Another student remarked that:

It was fun and it drove away dizziness during the lesson. (Student, 019)

There was a mention of the video watching enabling them to recall organic chemistry concepts they have learned and a student remarked that:

Watching the videos has helped me to recall things easily. Because it helped me to create mental picture of anything that I have learnt so far. (Student, 020)

Formative assessment

Further results from the Exit cards indicated that 9(16.6%) of the students found the classwork they did as most interesting. The lesson was structured in such a way that after students watched videos of the concepts to be learned, they were instructed to interact with one another in their respective groups to establish their understanding of the concepts viewed. The students were required to share their ideas and provide answers to the questions in order to solve the problems. This strategy was applied to assess their conceptual comprehension of organic chemistry. The teacher then requested from each group to present their solutions to the entire class. This allowed the students to exhibit their understanding of organic chemistry concepts to both themselves and their teacher (Tuckman & Monetti, 2011). This is consistent with Thorndike's exercise law, which stated that if an individual practices the new information, the conceptual understanding will improve (Schunk, 2004). For example, there was a mention of solving problems in groups, and a student remarked that

> *The most interesting part of the organic chemistry lesson was when students were solving and presenting their group work to the class, this is because after watching the video concerning organic chemistry students were able to do every trial question given to them.* (Student, 021)

Another student mentioned more work examples and positive feedback from the teacher and remarked that:

> *The examples of questions given to us to try kept us aware and focussed on the lesson to follow up more details from the teacher.* (Student, 007)

Another student remarked that:

> *Because organic chemistry has been challenging for, so to be able to assess myself and know my weakness so that I can improve myself.* (Student, 018)

Another student remarked that:

> *The examples of questions given to us to try kept us aware and focussed on the lesson to follow up more details from the teacher.* (Student, 013)

Situated learning

Another interesting result is that 14(25.9%) of the students referenced situated learning as the most interesting aspect of the instruction. The instructional strategy ensured that students sat and watched the videos on organic chemistry concepts in groups. The teacher divided the students into groups and gave each group a worksheet with questions related to the concepts covered in class. The students were required to share their ideas and provide answers to the questions in order to solve the problems. This strategy was applied to assess their conceptual comprehension of organic chemistry. The teacher then requested that each group present their solutions to the entire class. This allowed the students to exhibit their understanding of organic chemistry concepts to both themselves and their teacher (Mills, 2013). For example, there was a mention of the sharing of ideas and solving problems in groups, and a student remarked that

> *The most interesting part of the lesson was the group discussion. I'm saying this because during the group discussion I got to understand whatever that I was taught*. (Student, 014)

Another student remarked that

> *Through the group discussion I was able to express my views on the exercise and try work that was given to test our understanding and also had a good interaction with my colleague students especially the girls.* (Student, 006)

Sequence of instruction

Further results from the Exit cards indicated that 2(3.8%) of the students considered the sequence of the lesson as the most interesting aspect of the instruction. At Step 2 of the instructional strategy, the instructional objectives were outlined to the students in order to help them adequately appreciate the direction and intended learning outcome. Additionally, it was intended to trigger any prior knowledge they might have regarding the topic, allowing for effective knowledge transfer. Thus, facilitating the activation of the students' mental process (Gagné et al., 1992). For example, there was a mention that the lesson presentation was clear and sequential, and a student remarked that

The clear description of the learning objectives reminded me on the significant aspect to focus on and study. (Student, 012)

Another student remarked that

I am very interested in organic chemistry lesson due to the projection of the lesson which made me to focus on what the teacher is talking about. (Student, 016)

The results indicated as illustrated in Figure 6 that video-based learning, formative assessment, situated learning, and Gagne Nine Event of Instruction (Sequence of Instruction) were the identified theories intimately interlaced in the TB-OCIP model developed and employed in the teaching and learning of organic chemistry (Ghanizadeh, Hoorie, & Jahedizadeh, 2020; Green & Tolman, 2019). Moreover, the results indicate that a significant proportion of the students referenced video viewing in the teaching and learning process which align with the finding at the preliminary stage of the study on students preferred method of teaching. The students intimated that the use of video as an integral part of the teaching and learning of organic chemistry was a novelty and a new experience for them, which immensely contributed to their interest, problem-solving skills, comprehension, and class participation. According to the students, the visualization of organic compounds molecule through video simulations allowed them to appreciate the 2D and 3D presentation which could lead to the comprehension of naming and drawing structures of organic compounds (Rice, 2016; Sarkodie & Adu-Gyamfi, 2015). Further, the students asserted that the community of practice component, where the students were tasked with class activities and transitioned into the role of experts as they departed from group-based activities into individual-based tasks, contributed profoundly to their conceptual progression and class participation (Lave & Wenger, 1991). In addition, the students were of the view that the instructional strategy provided the opportunity to engage in more class exercises with prompt feedback. As a result, they were able to measure their performance in the conceptualization of organic chemistry, enhancing their problem-solving skills, procedural knowledge and aiding the control of their own learning processes (Bennett, 2011; Black & William, 1998). The students acknowledged that the instructional strategy delivered the lesson stepwise with adequate explanation of concepts with clarity. This enhanced their focus on the lesson and monitored the progress of the lesson in lieu of the expected learning outcomes (Gagne et al., 1992; Gündodu, 2016). The chronology of accounts stipulates that the preparation of an organic chemistry lesson plan based on TB-OCIP has the potential to empower organic chemistry students to be active participants in class, attentive learners, retain information, be self-motivated, and develop conceptual understanding (Sousa, 2016).

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

This chapter provides a comprehensive summary of the study's results, together with its derived conclusions and suggestions for future research in organic chemistry education. Furthermore, this chapter provides a reflective narration of the design-based research methodology employed in conducting the present study, which aimed to help the development of final design guidelines and highlight the significant findings of the research.

Summary

The study was purposed to improve teaching and learning organic chemistry in senior high schools. To achieve this purpose, DBR approach adopted as the research design for this study, that employed both quantitative and qualitative methodologies. Thus, data for the study was collected using semi-structured group interviews, semi-structured one-on-one interviews, pre- and post-test, questionnaires, field notes, and exit cards. The utilisation of a variety of data sources facilitated the research by employing a triangulation approach, which offers a degree of flexibility in generating a comprehensive and well-supported explanation for improvement of students' learning organic chemistry. In this DBR approach sampling was achieved through multistage sampling procedures as the various stages of this DBR demanded one or two different sampling techniques.

In using the DBR approach, at the preliminary stage of the study, 276 students and 9 teachers from seven schools in Kumasi Metropolis in the Ashanti Region were involved in the study. Seven SHS 3 intact classes were subsequently selected randomly from a randomly selected seven schools offering the General Science programme. This gave a sample size of 276 science students and 9 chemistry teachers teaching SHS 3 classes. The teachers and students were interviewed on the barriers and opportunities in the teaching and learning organic chemistry. Further, the students' responded to a two-tier multiple choice and short-answer diagnostic test on organic chemistry. The outcome of the Preliminary phase of the study clearly defined the problem of teaching and learning organic chemistry in the SHS, contributing to the design and development of the instructional strategy, theory-based organic chemistry instructional plan (TB-OCIP) at the design and development phase of the DBR approach. TB-OCIP underwent a process of refinement and validation by experts in chemistry education prior to the preparation for implementation in a real-life classroom teaching and learning processes.

At the implementation and assessment phase, TB-OCIP was used in five teaching try-outs lessons with 22 SHS 2 science students in the 2022/2023 academic year. An intact class was selected randomly from one of the seven schools engaged in the preliminary phase. A pre-test was conducted before the five lessons and a post-test at the end of the five lessons. At the end of each lesson, pre-structured survey (exit cards), and group interviews were conducted to allow students to share their perspectives on aspects of the lesson that they found interesting and challenging. They were also encouraged to provide reasons for their views and offer suggestions for improving the TB-OCIP-based lessons. Also, students were made to respond to a 5-point Likert scale questionnaire which measured their perception on the TB-OCIP delivered instruction to measure the efficacy and effectiveness of the TB-

OCIP as an instructional strategy on students' conceptual understanding of organic chemistry in the SHS.

The final phase of the DBR approach facilitated critical analysis and comprehensive recording of the whole research process. The comprehensive reflection and documentation of the whole study process enabled theory formulation for the generation of efficacious TB-OCIP based lessons.

Within the four stages of DBR approach, both quantitative and qualitative datasets were collected with a variety of research instruments as mentioned earlier. The quantitative datasets were analysed using percentages, means, and standard deviations to investigate the barriers to students' conceptual understanding of organic chemistry. Additionally, Wilcoxon signed-rank statistic was used to investigate the improvement in conceptual understanding of students in organic chemistry. The qualitative datasets were analysed through thematic analysis to arrive at themes with their accompanying sample statements.

Key Findings

1. Findings on the exploration of barriers and opportunities of teaching and learning organic chemistry in the perspectives of students and their teachers are:
   a) Students exhibited difficulties in comprehending various organic chemistry concepts as barriers to learning organic chemistry. That is, students were at the low level of conceptual understanding of organic compound concepts, such as reactions, isomerism, naming and drawing organic compounds, identifying functional groups, and the physical and chemical properties of organic compounds.

b) Students viewed there were several barriers accounting for their low level conceptual understanding of organic chemistry in the SHS. That is, there were barriers to learning chemistry (such as learning organic chemistry only in the extra tuition class) and barriers to teaching (where individual students found their way in organic chemistry without teacher guidance).

c) Students viewed there were preferred ways to teaching organic chemistry concepts to the understanding of students. That is, students viewed that if teachers adapt to teaching organic chemistry through video assisted teaching, step-by-step presentation, explanatory methodology, organic chemistry game simulations, and practical teaching.

d) Teachers viewed that there were several barriers to teaching organic chemistry concepts in the SHS leading to students' demonstration of low level of conceptual understanding. That is, teachers viewed that lack of practical materials, students' attitudes, poor concept introduction, and lack of opportunities (such as instructional materials) to engage students.

e) Teachers and students viewed that the identified barriers will affect teaching organic chemistry in the SHS in four ways. That is, the barriers will affect student desire to learn, abstract teaching and learning, student memorisation, and effective teaching of organic chemistry.

f) Teachers viewed that the effects of the identified barriers could be reduced by implementing four measures. That is, teachers viewed that right proportions of practical and theory lessons, concept sequencing teaching strategy, engagement of professional teachers, and teacher professional development could reduce the effects of the identified barriers to teaching and learning organic chemistry.

g) Teachers currently employed a range of teaching methods in teaching organic chemistry in the SHS. That is, teachers used brainstorming, enquiry, demonstration, exposition, videos, and online simulations in teaching organic chemistry.

h) Teachers viewed that implementing a practical-based and a video-based approaches were deemed as the most appropriate teaching methods for effectively teaching organic chemistry.

2. Findings on the exploration on design and development of an alternative intervention for teaching and learning organic chemistry in the SHS showed there can be another. That is, based on the findings in the preliminary research on barriers and opportunities and reviewed literature, TB-OCIP was designed and developed with the Gagne nine instructional sequence framework as the main theoretical underpinning.

    a. TB-OCIP as an alternative intervention is sequenced as gaining attention of students, recalling of previous knowledge, outlining learning objectives, presenting content, providing learning guidance, eliciting performance, providing feedback, assessing performance, and enhancing retention and transfer.

   b. TB-OCIP is the alternative intervention because it incorporates situated learning approach, formative assessment, and video-based learning.

3. Findings on examination on the impact of TB-OCIP on the conceptual understanding of students in learning organic chemistry showed that TB-OCIP can help improve students' conceptual understanding of organic chemistry in the SHS.
   a. Students performed creditably well learning organic chemistry through TB-OCIP. That is, students' scores in the post-test were higher compared to their scores in the pre-test.
   b. Students improved in all aspects of organic chemistry used in this study after learning through the intervention, TB-OCIP. That is, the results of the Wilcoxon signed rank statistic comparing post-test scores to pre-test scores showed that students' performance in organic compound concepts improved.
   c. Students improved in their conceptual understanding of organic chemistry after learning through TB-OCIP intervention. That is, students' explanations in the post-test on organic chemistry concepts were improvement of their explanations in the pre-test.
4. Findings on the examinations of perspectives of students on learning organic chemistry through TB-OCIP are:

a. Students had positive perception of learning organic chemistry through TB-OCIP. That is, students' positive perception was due to the active, delivery, understanding, and motivation nature of TB-OCIP that impact their learning of organic chemistry.

b. Students had positive experience learning organic chemistry through TB-OCIP intervention. That is, students felt learning organic chemistry through TB-OCIP was successful and interesting. Students viewed learning organic chemistry through TB-OCIP was effective. That is, the effectiveness of TB-OCIP intervention was due to instructional activities and multimedia.

c. Though students viewed learning organic chemistry with TB-OCIP was effective there were some challenges with the video and PowerPoint graphics.

d. Students made some suggestions for the improvement of using TB-OCIP in teaching organic chemistry in the SHS. That is, there should be collaborative activities, formative assessment, and video graphics should be improved.

Conclusion

This study investigated teaching and learning organic chemistry in the senior high schools in Kumasi Metropolis in the Ashanti Region. In doing this, an intervention (TB-OCIP) was designed and developed to help students overcome their low level conceptual understanding of organic chemistry in a design-based research approach. Initially, the findings of this research showed that students have conceptual difficulties in learning of organic chemistry as a result of their low level conceptual understanding of organic chemistry. This finding has broadened the knowledge on conceptual difficulties in learning organic chemistry as reported by WAEC Chief Examiners (WAEC, 2011; 2012; 2013; 2014; 2015; 2016; 2017; 2018; 2019; 2020; 2021) and other empirical studies (Adu-Gyamfi et al., 2012; 2013; Bhattacharyya & Bodner, 2005; Jimoh, 2005; Johnstone, 2006; Johnstone, 2010; Kurbanoglu et al., 2006; O'Dwyer & Childs, 2017; Uchegbu et al., 2016; Woldeamanuel et al., 2014). Not only is conceptual difficulties barrier to teaching and learning organic chemistry, there were a number of barriers such as barrier to learning, barrier to teaching, and lack of experimental resources. However, teaching through video assisted teaching, simulations, practical-based, and a balance of theory and practical teaching will help eliminate these barriers to teaching and learning organic chemistry in senior high schools.

The study was carried out to design and implement an instructional strategy to improve the teaching and learning of organic chemistry. The study has revealed that a theory-based organic chemistry instructional plan (TB-OCIP) which blended Gagne nine event of instruction, situated learning, formative assessment and video-based learning was an appropriate instructional strategy to enhance teaching organic chemistry in the senior high school. This study has contributed to the literature by providing chemistry educators and researchers an alternative instructional strategy to teaching and learning organic chemistry in the senior high school. This alternative could be the solution to learning chemistry as it blends situated learning approach, formative assessment, and video-based learning in a single instruction

The findings have showed that conceptual difficulties emanating from low level conceptual understanding in organic chemistry can be overcome when students are exposed to learning chemistry through TB-OCIP. That is, TB-OCIP was effective instructional strategy in this study, because students involved in this study improved in their conceptual understanding by learning organic chemistry through TB-OCIP. Indeed TB-OCIP is an alternative instructional strategy as it helped students to overcome their alternative conceptions in learning organic chemistry.

The findings have showed that not only is TB-OCIP improving students conceptual understanding of organic chemistry, it changed the perception of students. That is, students were of positive perception learning organic chemistry through TB-OCIP. It is important to have had such impact of TB-OCIP on students' perception because it has been reported severally that students perceive organic chemistry as difficult and lack interest in it. The positive students' perception was as a result of instructional activities and multimedia characteristics of learning chemistry with TB-OCIP.

Contribution to Knowledge

This study introduces an innovative instructional strategy known as the Theory-Based Organic Chemistry Instructional Plan (TB-OCIP). This lesson delivery plan uniquely combines Gagne's nine events of instruction, situated learning, formative assessment, and video-based learning. The design specifically aims to improve the teaching and learning of organic chemistry at the senior high school level in Ghana. A noteworthy aspect of this study is the use of a Design-Based Research (DBR) approach to develop, design, and refine TB-OCIP through various stages of implementation and evaluation.

The study significantly contributes to the field of chemistry education by proving TB-OCIP's effectiveness in improving students' conceptual understanding of organic chemistry. Research findings indicate that students exposed to TB-OCIP exhibited remarkable improvements in their grasp of organic chemistry concepts, effectively overcoming common conceptual challenges. Additionally, this strategy positively changed students' perceptions of the subject, addressing the widespread issue of students finding organic chemistry difficult and unengaging.

The study validates the efficacy of TB-OCIP as a robust teaching tool, adaptable for teaching other chemistry concepts, by employing both quantitative and qualitative methods. This comprehensive evaluation confirms TB-OCIP's potential as a valuable instructional strategy in the chemistry education domain.

Moreover, the study offers practical guidelines and theoretical frameworks for educators and instructional designers. These contributions enrich the existing knowledge on effective teaching practices in chemistry education, providing a solid foundation for future instructional design and implementation in this field.

Recommendation

The following recommendations are made based on the findings of the study:

1. As barriers to teaching and learning organic chemistry are seen as learning barriers and teaching barriers, science educators and researchers should investigate further the true nature of these barriers and how they predict conceptual difficulties in learning organic chemistry in the senior high school.

2. As TB-OCIP is an alternative instructional strategy for teaching organic chemistry, chemistry educators and researchers could further investigate to ascertain its efficacy in other chemistry lessons in naturalistic environment.
3. Since the implementation of the theory-based organic chemistry instructional plan (TB-OCIP) resulted in significant improvements in students' conceptual understanding and performance in organic chemistry, senior high school administrators in partnership with the monitoring and supervision unit of the Ghana Education Service to, organise professional development programmes to provide chemistry teachers with the needed knowledge to utilise TB-OCIP effectively in teaching chemistry concepts.
4. As students acknowledged the student-centred, participatory, and engaging nature of TB-OCIP lessons, as well as its positive impact on learner motivation in teaching and learning organic chemistry, chemistry teachers should adopt TB-OCIP for teaching and learning chemistry concepts in the senior high school.

Suggestions for Further Research

The purpose of the study was to evaluate the effect of TB-OCIP on students' conceptual understanding of organic chemistry. Nonetheless, it is important to recognize that the senior high school chemistry curriculum contains other challenging chemistry concepts that require greater conceptual comprehension among students. It is, therefore, strongly recommended that future studies investigate and assess the efficacy of TB-OCIP in tackling these challenging chemistry concepts at the high school level.

The study's focus was to improve the teaching and learning of organic chemistry for senior high school students. However, the study did not investigate teachers' conceptual understanding of organic chemistry concepts. Therefore, it is suggested that future research projects examine teachers' comprehension of organic chemistry concepts. This would provide a broader understanding of the subject and its pedagogical implementation.

This study only used a single group pre-test-post-test quasi experimental design to examine how effective TB-OCIP will be on students' learning of organic chemistry. This current study failed to control the experiment. It is, therefore recommended that further research be conducted to compare the effectiveness of TB-OCIP to other known effective instructional strategies on teaching and learning chemistry.

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APPENDICES

APPENDIX A

ORGANIC CHEMISTRY CONCEPTUAL UNDERSTANDING SCALE (OCCUS-1)

Introduction

This questionnaire is strictly for academic purposes and you are assured of confidentiality and anonymity. I hope that you will feel free to respond to the questions frankly as possible, as you will be contributing enormously to this study.

Instructions

Kindly circle the correct option from the multiple-choice items (1-11) and provide the corresponding reasons for your choice of option. Item 12-22 are open-ended items that require you to provide responses to the first part and give reasons for your choice of response. Please note that item 17 does not require any reasons for your response.

Sex: Male [ ] Female [ ]

1. An example of an alkene molecule is …………………………………

(a) $CH_3CH_2CHCH_2$

(b) $CH_3CH_2CH_2CH_3$

(c) $CH_3CH_2CH_2Cl$

(d) CH_3CH_2CCH

Give reason:

……………………………………………………………………………………

……………………………………………………………………………………

……………… …………………………………………………………………

2. Dehydration of an alcohol leads to the formation of an _____ .

(a) alkene

(b) alkane

(c) alkyne

(d) alkyl halide

Give Reasons:

………………………………………………………………………………………

………………………………………………………………………………………

……………….…………………………………………………………………………

3. The following organic molecules exhibit geometric isomerism except?

(a) 1-hexene

(b) 2-hexene

(c) 3-hexene

(d) 4-hexene

Give Reason:

………………………………………………………………………………………

………………………………………………………………………………………

……………………………….

……………………………………………………………………………

4. Which compound would have the highest boiling point?

(a) $CH_3CH{=}CHCH(CH_3)_2$

(b) $CH_3CHClCH_2CH_2CH_3$

(c) $CH_3CH_2CH_2CH_2CHCH$

(d) $CH_3CH_2CH_2CH_2CH_2OH$

Give reason:

………………………………………………………………………………………

………………………………………………………………………………………

……………………………………………………………………………………….

5. Identify the secondary alcohol amongst the following alcohol molecules.

(a) $CH_3CH(OH)CH_3$

(b) CH_3CH_2OH

(c) $(CH_3)_3COH$

(d) $CH_3CH(OH)_2$

Give reason:

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………..

6. Two isomeric forms of a saturated hydrocarbon have ………………………

(a) different compositions of elements.

(b) different content of the isotopes of hydrogen.

(c) the same structure.

(d) the same molecular formula.

Give reason:

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………..

7. What is the expected product formed from the reaction between 2-butene and Cl_2?

(a) 1-chlorobutane

(b) 2-chlorobutane

(d) 2,2-dichlorobutane

(c) 2,3-dichlorobutane

Give reason:

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………….

8. Hexane and 3-methylpentane are examples of one of the following.

a) Diastereomers.
b) Enantiomers.
c) Stereoisomers.
d) Structural isomers.

Give reason:

…………………………………………………………………………………

…………………………………………………………………………………

………………………………………………………………………………….

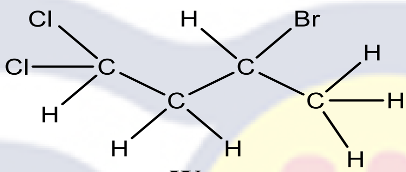
9. The organic starting materials for the preparation of an ester could be a/an…………………

a) alkene and water
b) alkene and Chromic Acid
c) carboxylic acid and an alcohol
d) ketone and Potassium permanganate

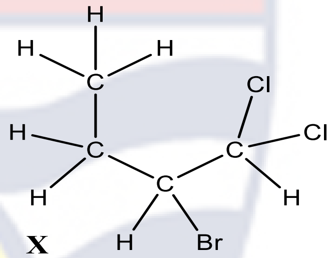
Give reason:

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

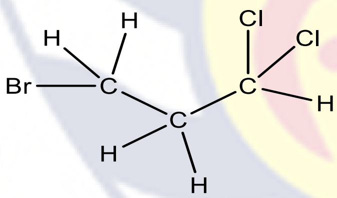
10. From the four compounds W, X, Y, Z are represented below. indicate which of them are isomers.



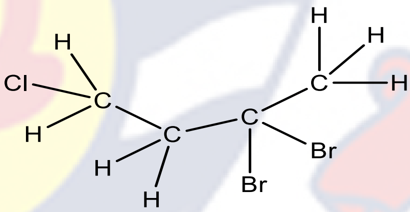
W



X



Y



Z

A. W and Y
B. X and Y
C. W and X
D. Y and Z

Give reason:

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

11. Which of the compound in the following pair would have the higher boiling point

a. $CH_3(CH_2)_4CH_3$ or b. $CH_3(CH_2)_7CH_3$

……………………………

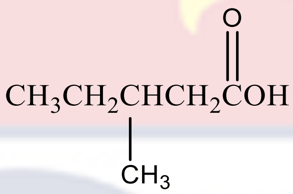
Give reason:

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………

12. Rewrite the formula of the compound below using the bond-line formula



……………………………

Give reason:

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

13. Write the dash formula for all the structural isomers with the molecular formula C_4H_{10}

……………………………………………………………………………………..

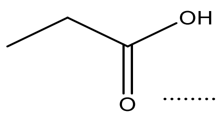
Give reason:

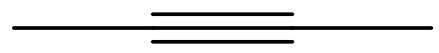
……………………………………………………………………………………

……………………………………………………………………………………

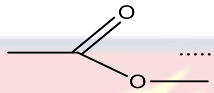
……………………………………………………………………………………

14. Identify the functional group in each of the following compounds and state the reason

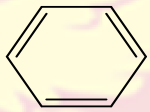
a  ....

b.  ....

c.  ....

d.  ....

e.  ....

f.  ....

Give reason:

a. ……………………………………………………………………………………

b. ……………………………………………………………………………………

c. ……………………………………………………………………………………

d. ……………………………………………………………………………………

e. ……………………………………………………………………………………

f. ……………………………………………………………………………………

15. Provide the reagents for the following transformation.

$$CH_3CH{=}CH_2 \longrightarrow CH_3CH_2CH_3$$

………………………………….

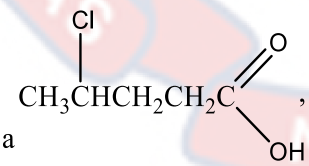
Give reasons:

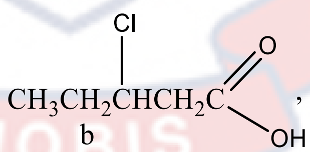
……………………………………………………………………………………

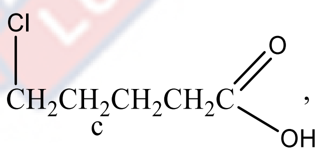
……………………………………………………………………………………

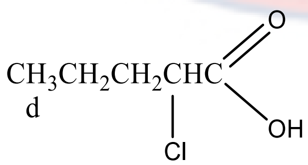
……………………………………………………………………………………..

16. Arrange the following compounds in order of increasing acidity


a


b


c


d

……………………………………………………………………………………

Give reasons:

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

17. Draw the structural formula for the following organic compounds

a. Octane

……………………………………………………………………

b. 2-heptene

……………………………………………………………………

c. Hexyne

……………………………………………………………………

d. 2,2-dimethylpentane

……………………………………………………………………

e. Heptanol

……………………………………………………………………

f. Propanoic acid

……………………………………………………………………

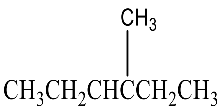
g. Ethyl pentanoate

……………………………………………………………………

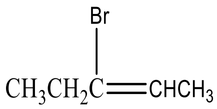
h. 1-bromobenzene

……………………………………………………………………

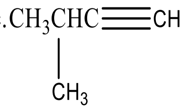
18. Use the IUPAC rules to name the organic molecules below

a. 

....

b. 

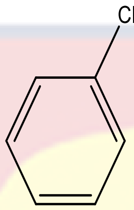
....

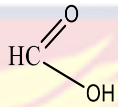
c. 

....

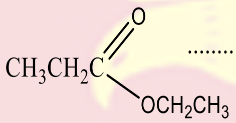
d. $CH_3CH_2CH_3$

....

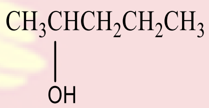
e. 

f. 

....

g. 

....

h 

....

Give reasons

a. ....

b. ....

c. ....

d. ....

e. ....

f. ....

g. ....

h. ....

19. Give the product (if any) formed in the reactions below:

a. $CH_3C\equiv CCH_3 \xrightarrow{\text{excess } H_2,\ Pt}$

Give reason:

....

....

....

b. $H_2C=CH_2 + H_2O \xrightarrow{H^+}$

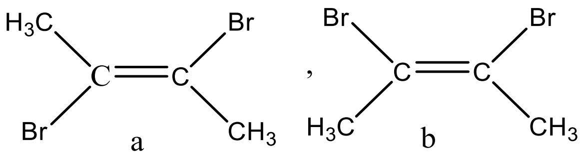
Give reason:

....

....

....

20. The relationship between the structures below could be described as?



……………………………………………………………………..

Give reasons

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

21. Consider the three isomeric alkanes: n-hexane, 2,3-dimethylbutane, and 2-methylpentane. Arrange them in order of decreasing boiling point?

………………………………………………………………………………

………………………………………………………………………………

………………………………

Give reason:

………………………………………………………………………………

………………………………………………………………………………

………………………………………………………………………………

22. What is the product formed when ethanol is treated with H_2CrO_4?

…………………………………………

Give reason:

………………………………………………………………………………

………………………………………………………………………………

……………………………………

APPENDIX B

ORGANIC CHEMISTRY CONCEPTUAL UNDERSTANDING SCALE

(OCCUS-2A)

Introduction

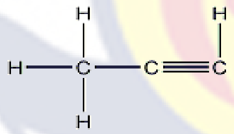
This text is strictly for academic purposes and you are assured of confidentiality and anonymity. I hope that you will feel free to respond to the questions frankly as possible, as you will be contributing enormously to my research.

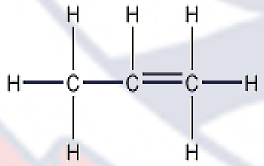
Instructions

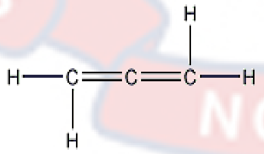
Kindly circle the correct option from the multiple-choice items (1–9) and provide the corresponding reasons for your choice of option. Item 10 is an open-ended item that requires you to provide the correct response. Please note that item 10 does not require any reasons for your response.

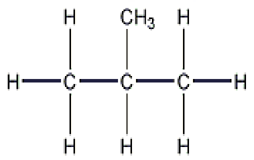
Sex: Male [ ] Female [ ]

1. Which of the following structures is INCORRECT?

A. 

B. 

C. 

D. 

Give reasons:

……………………………………………………………………………
……………………………………………………………………………
……………………………………………………………………………

2. The following statements regarding alkanes are true **EXCEPT**……?
   A. Alkanes are soluble in water
   B. Alkanes have low boiling points
   C. Alkanes are non-polar molecules
   D. Alkanes experience dispersion forces

Give reasons:

……………………………………………………………………………
……………………………………………………………………………
……………………………………………………………………………

3. Vegetable oil is made into margarine through ……………………….
   A. halogenation
   B. hydrogenation
   C. methylation
   D. oxidation

Give reasons:

……………………………………………………………………………
……………………………………………………………………………
……………………………………………………………………………

4. The functional group contained in the compound $CH_2=CH_2$ is a(n) ….
   A. carboxyl
   B. double bond
   C. hydroxyl
   D. triple bond

Give reasons:

……………………………………………………………………………
……………………………………………………………………………
……………………………………………………………………………

5. Which of the following is the concept of cis-trans isomerism possible?
   A. 1,1-dibromoethane
   B. 1,1-dibromoethene
   C. 1,2-dibromoethene
   D. 1,2-dibromoethyne

Give reasons:

……………………………………………………………………………
……………………………………………………………………………
……………………………………………………………………………

6. The carbon-carbon triple bond of an alkyne is composed of ………
   A. 1 sigma bond and 2 pi bonds
   B. 2 sigma bonds and 1 pi bond
   C. 3 pi bonds and I sigma bond
   D. 3 sigma bonds and 1 pi bond

Give reasons:
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

7. Which of the following is a common reaction of alkynes with palladium catalyst and hydrogen gas to form an alkane?
   A. Halogenation
   B. Hydrogenation
   C. Oxidation
   D. Reduction

Give reasons:
……………………………………………………………………………………
……………………………………………………………………………………
…………………………………………………………………………………

8. Alkynes show cis-trans isomerism in their molecules.
   A. False
   B. True

Give reasons:
……………………………………………………………………………………
……………………………………………………………………………………
………………………………………………………………………

9. Alkynes are more reactive than alkenes.
   A. False
   B. True

Give reasons:
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

10. Draw the structural formula for 1-chloro-2,2-dimethylpentane

APPENDIX C

ORGANIC CHEMISTRY CONCEPTUAL UNDERSTANDING SCALE

(OCCUS-2B)

Introduction

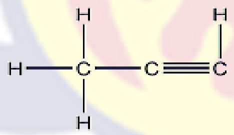
This text is strictly for academic purposes and you are assured of confidentiality and anonymity. I hope that you will feel free to respond to the questions frankly as possible, as you will be contributing enormously to this study.

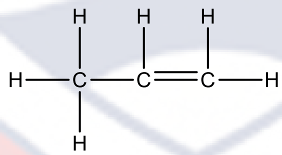
Instructions

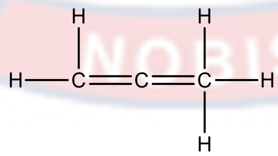
Kindly circle the correct option from the multiple-choice items (1–9) and provide the corresponding reasons for your choice of option. Item 10 is an open-ended item that requires you to provide the correct response. Please note that item 10 does not require any reasons for your response.

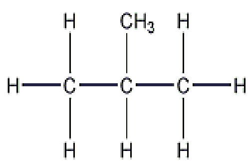
Sex: Male [ ] Female [ ]

1. Which of the following structures is INCORRECT?

A. 

B. 

C. 

D. 

Give reasons:

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………

2. Alkanes have low boiling point that alkenes,
   - A. False
   - B. True

Give reasons:
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

3. The reaction between an alkene molecule and hydrogen in the presence of a catalyst (Pd) is none as___________
   - A. halogenation
   - B. hydrogenation
   - C. methylation
   - D. oxidation

Give reasons:
……………………………………………………………………………………
……………………………………………………………………………………
…………………………………………………………

4. The functional group contained in the compound $HC\equiv CH$ is a(n) ….
   - A. carboxyl
   - B. double bond
   - C. hydroxyl
   - D. triple bond

Give reasons:
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

5. Which of the following is the concept of cis-trans isomerism possible?
   - A. 1,1-dichloroethane
   - B. 1,1-dichloroethene
   - C. 1,2-dichloroethene
   - D. 1,2-dichloroethyne

Give reasons:
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

6. The carbon-carbon double bond of an alkene is composed of ....
   A. 1 sigma bond and 1 pi bond
   B. 2 sigma bonds and 1 pi bond
   C. 3 pi bonds
   D. 3 sigma bonds

Give reasons:
....
....
....

7. Which of the following statements about the reactivity of alkynes is true?
   A. Alkynes are less reactive than alkanes.
   B. Alkynes are more reactive than alkanes but less reactive than alkenes.
   C. Alkynes are more reactive than alkenes.
   D. Alkynes are not reactive at all.

Give Reasons
....
....
....

8. Alkynes do not show cis-trans isomerism in their molecules.
   A. False
   B. True

Give reasons:
....
....
....

9. Alkenes are more reactive than alkynes.
   A. False
   B. True

Give reasons:
....
....
....

10. Draw the structural formula for 1-bromo-2-methylhex-1-ene.
....
....
....
....

Give reasons:
....
....
....

APPENDIX D

ORGANIC CHEMISTRY TEACHERS' INTERVIEW SCHEDULE (OCTIS)

1. Have you taught your students organic chemistry?
2. How long have you been teaching organic chemistry in the SHS?
3. Are there identifiable challenges and opportunities linked to the instruction and acquisition of organic chemistry?
4. Explain the potential impact of these identifiable challenges on the teaching and learning of organic chemistry.
5. Explain the measures that ought to be undertaken to mitigate the impact of the identifiable challenges linked to the instruction and acquisition of organic chemistry.
6. How do you teach organic chemistry to your students?
7. What should be the appropriate strategy for teaching and learning organic chemistry?

APPENDIX E

ORGANIC CHEMISTRY STUDENTS' INTERVIEW SCHEDULE (OCSIS)

1. Have you been taught any topic under organic chemistry?
2. Provide a rationale for your selection of this option (incorrect choice) as your response to this question.
3. What are the challenges you encounter in learning organic chemistry?
4. Are there any challenges in the teaching and learning of organic chemistry in this school?
5. How have your teachers been teaching you organic chemistry?
6. How do you want to be taught organic chemistry?

APPENDIX F

ORGANIC CHEMISTRY INTERVENTION INTERVIEW SCHEDULE (OCIIS)

1. How will you assess today's lesson? Was it successful or unsuccessful?
2. Were the instructional activities and media used relevant to the organic chemistry topics taught?
3. To what extent did the lesson delivery encourage interaction?
4. What flaws do you observe in the lesson delivery?
5. What strengths in the lesson delivery should be maximized, in your opinion, for effective teaching and learning organic?
6. How can the lesson delivery be enhanced?

APPENDIX G

Science students Exit Cards

Please fill out this survey about the lesson

1. What was the most interesting thing/part/aspect of the organic chemistry lesson?

....
....
....
....
....
....
....
....

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....
....
....

APPENDIX H

ORGANIC CHEMISTRY INTERVENTION PERCEPTION SCALE (OCIPS)

I am conducting research and would appreciate your assistance. If you are willing to participate, it should take you between 5-10 minutes. I request that you complete a questionnaire designed to assess the efficacy of the instructional tool for teaching and learning organic chemistry.

The questionnaire consists of two sections. The first section is designed to collect your background information, and the second section is a list of statements to which you must indicate your agreement or disagreement by ticking the appropriate box. Your participation in this study is completely optional, and you have the right to discontinue your participation at any point without facing any negative consequences. Furthermore, it should be noted that your name will not be displayed in any search outcomes, and the confidentiality of your personal details will always be upheld.

Thank you for taking time to complete this survey.

Part I: Background Information

1. Sex: Male [ ]   Female [ ]

Part II: Efficacy of Intervention

Read the following statements carefully and indicate whether you agree or disagree by ticking in the appropriate box. Note: Strongly Disagree (SD), Disagree (D), Neutral (N), Agree (A), Strongly Agree (SA)

Statements	SD	D	N	A	SA
1. I was able to participate in the learning activity during the lesson delivery.					
2. There was active students' participation in the lesson.					
3. This way of teaching organic chemistry gave me the chance to interact with my classmates the whole time.					
4. In this lesson there were variety of activities with the common goal of engaging students in the lesson.					
5. Lesson instruction was more focused on the students.					
6. The lesson afforded me opportunities to work with my classmates to solve problems in organic chemistry.					
7. I understood the organic chemistry concepts through interaction with my classmates during the lesson.					
8. In this lesson, the teacher employed strategies that inspired me to collaborate with others to solve problems in organic chemistry.					
9. The lesson activities were designed to reflect real-world context.					
10. In this lesson, the teacher clearly defined the learning objectives that guided us to learning organic chemistry.					
11. The teacher continuously asked questions to monitor our progress throughout the lesson.					
12. The teacher provided feedback on our work to the class to facilitate learning.					
13. 1. The use of group activities in the lesson has increased my participation in organic chemistry lessons.					
14. I believe I will remember what I have learned in these lessons for a long time.					
15. This approach to teaching chemistry has increased my desire to learn organic chemistry.					
16. The use of video in the lesson made learning organic chemistry generally interesting.					
17. Through the use of videos in the lesson, I was able to comprehend why organic chemistry is perceived as difficult.					
18. This sequential method of instruction made the organic chemistry lessons understandable.					

APPENDIX I

Theory-Based Organic Chemistry Instructional Plan (TB-OCIP)

Lesson 1

Subject: Organic chemistry

Topic: Alkane

Subtopic: identification, naming, and drawing of alkane molecules

Duration: 120mumites

Learning resources: videos, ChemDraw software, electronic projector

- ChemDraw software: used for drawing chemical structures and reactions. It is considered a valuable learning resource for students studying chemistry as it allows them to visualize chemical structures and reactions in a digital format

Gain attention: In this initial stage of the lesson, the objective is to attract the students' attention. To do this, the teacher shows a brief video on the applications of Alkanes. Students watch video for 3 minutes and mention some practical application of alkanes.

Recall of previous knowledge: At this stage of instruction, the teacher will integrate the previous knowledge of students and the incoming alkane concepts to enable and attentive and expectant student to obtain mastery of alkane concept. The teacher reviews students' previous knowledge on covalent bonding in CH_4, N_2, and H_2O for 5 minutes.

Outlining learning objectives: After gaining the attention of students through showcasing a video on alkanes, teacher will stimulate students' cognitive processes by informing them of anticipated learning outcomes. The teacher states and shares the lesson's learning objectives with students in 5 minutes. By the end of this lesson, you should be able to:

1. Identify an alkane molecule using their general formula.
2. Write the names of alkane molecules using the IUPAC nomenclature
3. Draw the structures of alkanes base on the IUPAC names

Students acknowledge the lesson objectives by writing them in their note books.

Present content: The purpose of this stage of instruction is for the teacher to present the alkane concepts to be learned through a series of activities that involve the students. The teacher divides the students into five groups of seven members each. Subsequently, the teacher presents videos on the identification, naming, and structural presentation of alkanes, while the students watch attentively and take notes on important details for 18-minute. The teacher instructs the students to work together and share ideas in their designated groups on how to identify, name, and draw alkane compounds, encouraging them to engage in critical thinking and effective communication. Students respond by working together and sharing ideas in their assigned groups to outline the steps involved in identifying, naming, and drawing an alkane molecule for 5 minutes. Afterwards, the teacher selects three groups randomly to present their findings on the identification, naming, and drawing of alkanes. Students respond by presenting their findings to the entire class in 5 minutes each.

Provide learner guidance: The purpose of this instructional stage is to lead students through a step-by-step explanation, using PowerPoint and ChemDraw software, to help them learn and retain the concept. The teacher presents a 20-minute PowerPoint on identifying, naming, and drawing alkane molecules. Then, the teacher uses ChemDraw software to show students the 2D and 3D structural presentation of alkane molecules for 5 minutes.

Elicit performance (practice): The purpose of this stage of instruction is to activate students' thinking processes to aid in the internalization of the identification, naming, and drawing of alkane molecule structures, and to verify correct comprehension of these concepts. The teacher asks the groups to provide the names and structural formulas of various alkane molecules in the worksheet, as given figure 5:

ALKANES (WORKSHEET 1)

1. **Identifying an alkane molecule using their genral formula**

a). What is the general formula of alkanes?

answer: ____________________________

b). which of the following is an alkane molecule

1. C2H6
2. C2H8
3. C4H10
4. C5H12:

1.________________________

2.________________________

3.________________________

4.________________________

2. Writing the names of alkane molecules using the IUPAC name

a). Write the IUPAC name of the following alkane molecules:

1. CH_4 1.____

2. $CH_3CH_2CH_2CH_3$ 2.____

3. CH_3CHCH_3 (with CH_3 on the middle carbon) 3.____

3. Drawing the structures of alkanes base on the IUPAC names

a). Provide the structural formula of the following IUPAC named alkane molecules:

1. Heptane
2. 2-methylpentane
3. 2,2-dimethylpentane
4. 4-chloro-4-ethyloctane

Answer:

1.	2.
3.	4.

Figure 5: Worksheet for students group work

The teacher moves round to inspect work being done by the groups for 11 minutes.

Provide feedback: The goal is to provide immediate feedback for student on their progress. The teacher selects three groups randomly to present their solutions to the questions given in 10 minutes. The teacher provides immediate feedback on the group's presentation.

Assess performance: The purpose is to determine the degree of students' conceptual understanding in order to diagnose existing issues and provide further assistance. The teacher dissolves the groups and provides questions for students to solve individually on identifying, naming, and drawing various alkane molecules on the provided worksheet in figure 6:

ALKANES (WORKSHEET 2)

1. Identifying an alkane molecule using their genral formula

a). What is the general formula of alkanes?

answer: ____________________

b). which of the following is an alkane molecule

1. C6H14
2. C7H16
3. C2H4
4. C3H6

1. ____________________

2. ____________________

3. ____________________

4. ____________________

2. Writing the names of alkane molecules using the IUPAC name

a). Write the IUPAC name of the following alkana) e molecules:

1. $CH_3CH_2CH(CH_3)CH_3$ 1. ____________________
2. $CH_3Cl_2CH_2$ 2. ____________________
3. $CH_3CH_2CHBrCH(CH_3)CH_3$ 3. ____________________

3. Drawing the structures of alkanes base on the IUPAC names

a). Provide the structural formula of the following IUPAC named alkane molecules:

1. hexane
2. 2-methylpentane
3. 3-ethyl-2-methylhexane
4. 2,2,4-trimethylheptane

Answer:

1.	2.
3.	4.

Figure 6: Worksheet for students' independent work

Students respond by solving the questions given for 8 minutes. Teacher calls 7 students to present their solution to each of the questions and provides immediate feedback on the students' responses in 5 minutes.

Enhance retention and transfer: The purpose of this last stage pf instruction is to aid students in acquiring knowledge and internalising the alkanes concepts they had acquired in order to promote retention and transfer. The teacher asks students to review the processes involved in the identification, naming, and drawing of alkane molecules in 10 minutes. Students respond by reviewing what has been learned.

Lesson 2

Subject: Organic chemistry

Topic: Alkenes and Alkynes

Subtopic: identification, naming, and drawing of alkene and alkyne molecules

Duration: 120mumites

Learning resources: videos, ChemDraw software, electronic projector

- ChemDraw software: used for drawing chemical structures and reactions. It is considered a valuable learning resource for students studying chemistry as it allows them to visualize chemical structures and reactions in a digital format

Gain attention: In this initial stage of the lesson, the objective is to attract the students' attention. To do this, the teacher shows a brief video on the applications of alkenes and alkynes. Students watch video for 3 minutes and mention some practical application of alkenes and alkynes.

Recall of previous knowledge: At this stage of instruction, the teacher will integrate the previous knowledge of students and the incoming alkane concepts to enable an attentive and expectant student to obtain mastery of alkane concept. The teacher reviews students' previous knowledge on naming of alkanes for 5 minutes.

Outlining learning objectives: After gaining the attention of students through showcasing a video on alkenes and alkynes, teacher will stimulate students' cognitive processes by informing them of anticipated learning outcomes. The teacher states and shares the lesson's learning objectives with students in 5 minutes. By the end of this lesson, you should be able to:

4. Identify n alkene and alkyne molecules using their general formula.
5. Write the names of alkene and alkyne molecules using the IUPAC nomenclature
6. Draw the structures of alkenes and alkynes base on the IUPAC names

Students acknowledge the lesson objectives by writing them in their note books.

Present content: The purpose of this stage of instruction is for the teacher to present the alkane concepts to be learned through a series of activities that involve the students. The teacher divides the students into 6 groups of seven members each. Subsequently, the teacher presents videos on the identification, naming, and structural presentation of alkenes and alkynes, while the students watch attentively and take notes on important details for 18-minute. The teacher instructs the students to work together and share ideas in their designated groups on how to identify, name, and draw alkene and alkyne compounds, encouraging them to engage in critical thinking and effective communication. Students respond by working together and sharing ideas in their assigned groups to outline the steps involved in identifying, naming, and drawing an alkene and alkyne molecule for 5 minutes. Afterwards, the teacher selects three groups randomly to present their findings on the identification, naming, and drawing of alkenes and alkynes. Students respond by presenting their findings to the entire class in 5 minutes each.

Provide learner guidance: The purpose of this instructional stage is to lead students through a step-by-step explanation, using PowerPoint and ChemDraw software, to help them learn and retain the concept. The teacher presents a 20-minute PowerPoint on identifying, naming, and drawing alkene and alkyne molecules. Then, the teacher uses ChemDraw software to show students the 2D and 3D structural presentation of alkane molecules for 5 minutes.

Elicit performance (practice): The purpose of this stage of instruction is to activate students' thinking processes to aid in the internalization of the identification, naming, and drawing of alkene and alkyne molecule structures, and to verify correct comprehension of these concepts. The teacher asks the groups to provide the names and structural formulas of various alkene and alkyne molecules in the worksheet, as given in figure 1:

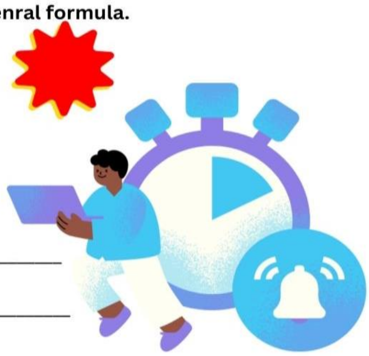
Alkenes and Alkynes (WORKSHEET 3)

1.**1. Identify an alkene and alkyne molecules using their genral formula.**

a). What is the general formula of the following:

Alkene: ___________________________________

Alkyne:___________________________________



1. b). Use the General formulas of alkenes and alkynes to write the condensed formula when n= 2, 5, 6.

Alkene: Alkyne:

n=2 ______________________ ______________________

n=5 ______________________ ______________________

n=6______________________ ______________________

1. Write the names of alkene and alkyne molecules using the IUPAC name

a). Write the IUPAC name of the following molecules:

$CH_3CH_2CH{=}CH_2$ 1.____

$CH_3CHCH_2CH_2CH{=}CHCH_2CH_3$ (with CH_3 on the second carbon) 2.____

$CH_3CHCH_2C{\equiv}CH$ (with CH_3 on the second carbon) 3. ____

3. Drawing the structures of the following molecules base on the IUPAC names

a). Provide the structural formula of the following IUPAC named alkane molecules:

1. Hept-2-ene
2. Oct-1-yne
3. 2,2-dimetylhex-1-ene
4. 4-chloro-4-ethylnon-2-yne

Answer:

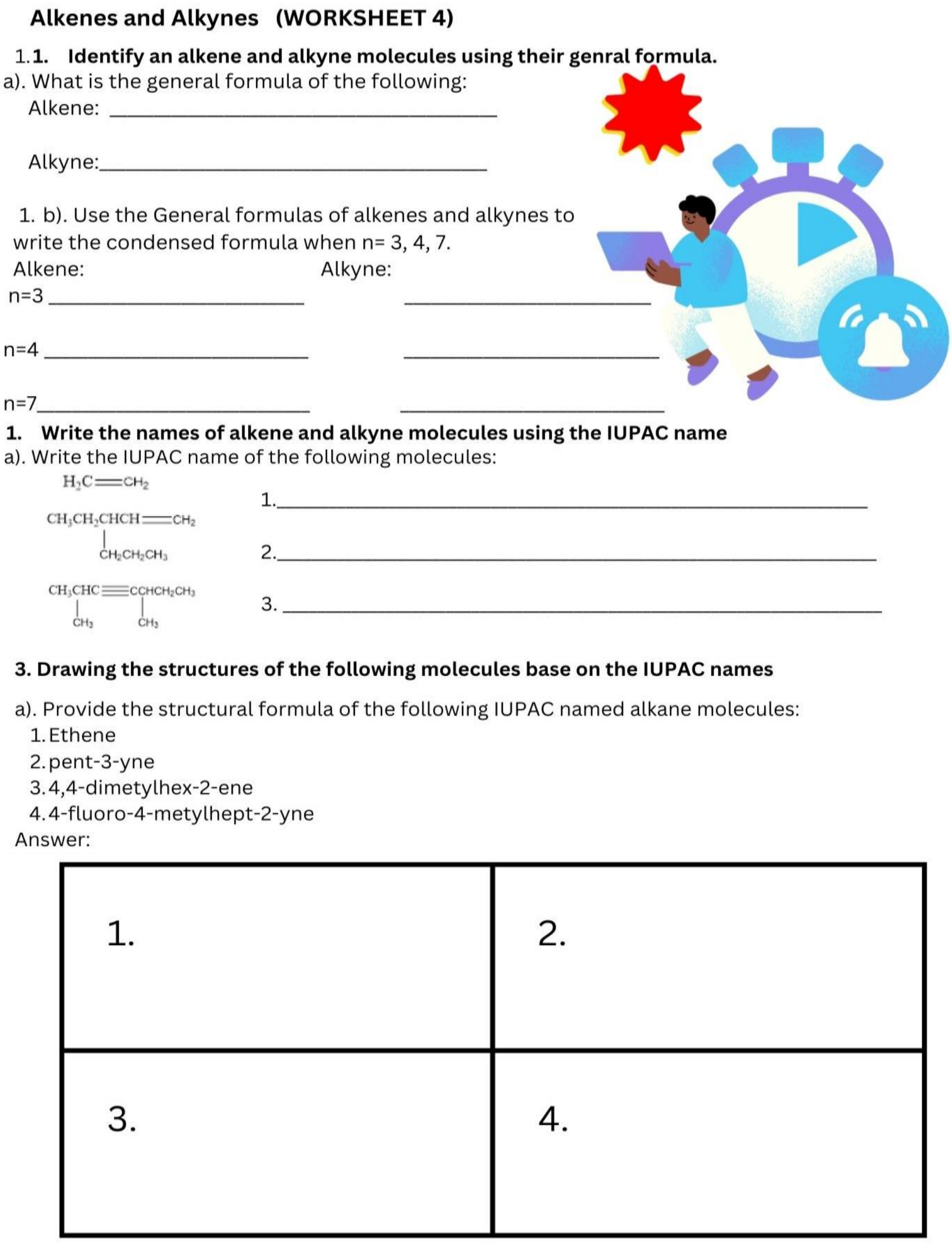
1.	2.
3.	4.

Figure 1: worksheet for students group work

The teacher moves round to inspect work being done by the groups for 11 minutes.

Provide feedback: The goal is to provide immediate feedback for student on their progress. The teacher selects three groups randomly to present their solutions to the questions given in 10 minutes. The teacher provides immediate feedback on the group's presentation.

Assess performance: The purpose is to determine the degree of students' conceptual understanding in order to diagnose existing issues and provide further assistance. The teacher dissolves the groups and provides questions for students to solve individually on identifying, naming, and drawing various alkene and alkyne molecules on the provided worksheet in figure 2:


Alkenes and Alkynes (WORKSHEET 4)

1.1. **Identify an alkene and alkyne molecules using their genral formula.**

a). What is the general formula of the following:

Alkene: ______________________________

Alkyne:______________________________

1. b). Use the General formulas of alkenes and alkynes to write the condensed formula when n= 3, 4, 7.

Alkene:	Alkyne:
n=3 ____________________	____________________
n=4 ____________________	____________________
n=7____________________	____________________

1. **Write the names of alkene and alkyne molecules using the IUPAC name**

a). Write the IUPAC name of the following molecules:

$H_2C{=}CH_2$ 1.____

$CH_3CH_2CHCH{=}CH_2$ with $CH_2CH_2CH_3$ 2.____

$CH_3CHC{\equiv}CCHCH_2CH_3$ with CH_3, CH_3 3. ____

3. Drawing the structures of the following molecules base on the IUPAC names

a). Provide the structural formula of the following IUPAC named alkane molecules:

1. Ethene
2. pent-3-yne
3. 4,4-dimetylhex-2-ene
4. 4-fluoro-4-metylhept-2-yne

Answer:

1.	2.
3.	4.

Figure 2: worksheet for students' independent work

Students respond by solving the questions given for 8 minutes. Teacher randomly calls 7 students to present their solution to each of the questions and provides immediate feedback on the students' responses in 5 minutes.

Enhance retention and transfer: The purpose of this last stage pf instruction is to aid students in acquiring knowledge and internalising the alkenes and alkynes concepts they had acquired in order to promote retention and transfer. The teacher asks students to review the processes involved in the identification, naming, and drawing of alkene and alkyne molecules in 10 minutes. Students respond by reviewing what has been learned.

Lesson 3

Subject: Organic chemistry

Topic: Hydrocarbons

Subtopic: 1. Isomerism in hydrocarbons (alkanes and alkenes)

2. Physical and chemical properties in alkanes

Duration: 120mumites

Learning resources: videos, ChemDraw software, models, electronic projector

- ChemDraw software: used for drawing chemical structures and reactions. It is considered a valuable learning resource for students studying chemistry as it allows them to visualize chemical structures and reactions in a digital format

Gain attention: In this initial stage of the lesson, the objective is to attract the students' attention. To do this, the teacher shows a short video on importance of chemistry to the society. Students watch video for 3 minutes to focus their attention on upcoming lesson.

Recall of previous knowledge: At this stage of instruction, the teacher will integrate the previous knowledge of students and the incoming isomerism in hydrocarbons, physical/chemical properties of alkanes, and preparation of alkanes concepts to enable an attentive and expectant student to obtain mastery of alkane concept. The teacher reviews students' previous knowledge on naming of alkenes and alkynes for 5 minutes.

Outlining learning objectives: After gaining the attention of students through showcasing a video on alkenes and alkynes, teacher will stimulate students' cognitive processes by informing them of anticipated learning outcomes. The teacher states and shares the lesson's learning objectives with students in 5 minutes. By the end of this lesson, you should be able to:

1. Define Isomerism in hydrocarbons and give examples.
2. Mention at least two Physical and chemical properties each in alkanes
3. Identify at least one method of preparation of alkanes

Students acknowledge the lesson objectives by writing them in their note books.

Present content: The purpose of this stage of instruction is for the teacher to present the alkane concepts to be learned through a series of activities that involve the students. The teacher divides the students into 6 groups of seven members each. Subsequently, the teacher presents videos on the isomerism in hydrocarbons, physical/chemical properties of alkanes, and preparation of alkanes while the students watch attentively and take notes on important details for 18-minute. The teacher instructs the students to work together and share ideas in their designated groups on isomerism in hydrocarbons, physical/chemical properties of alkanes, and preparation of alkanes encouraging them to engage in critical thinking and effective communication. Students respond by working together and sharing ideas in their assigned groups on isomerism in hydrocarbons, physical/chemical properties of alkanes, and preparation of alkanes for 5 minutes. Afterwards, the teacher selects three groups randomly to present their findings on isomerism in hydrocarbons, physical/chemical properties of alkanes, and preparation of alkanes. Students respond by presenting their findings to the entire class in 5 minutes each.

Provide learner guidance: The purpose of this instructional stage is to lead students through a step-by-step explanation, using PowerPoint and ChemDraw software, and models, to help them learn and retain the concept. The teacher presents a 20-minute PowerPoint on isomerism in hydrocarbons and physical/chemical properties of alkanes. Then, the teacher uses ChemDraw software and models to show students the 2D and 3D structural presentation of isomerism in hydrocarbons for 5 minutes.

Elicit performance (practice): The purpose of this stage of instruction is to activate students' thinking processes to aid in the internalization of isomerism in hydrocarbons, physical/chemical properties of alkanes, and preparation of alkanes and to verify correct comprehension of these concepts. The teacher asks the groups to provide answers to questions on isomerism in hydrocarbons, physical/chemical properties of alkanes, and preparation of alkanes in the worksheet, as given in figure 1:

1. **Define Isomerism in hydrocarbons and give examples.**

a) What is isomerism in hydrocarbons?

____
____
____
____
____
____

b) Which of the compounds below are cis-trans isomers possible?

A. CH3CH=CH2
B. CH3CH=CHCH3
C. CH3CH=CHCH2CH3

2. **Physical and chemical properties each in alkanes**

a)The reaction of propane with bromine is called? ______________________________

b) Which of the following alkanes has the lowest boiling point?

A. Butane
B. Hexane
C. Pentane
D. Propane

Give reasons for the selected option

____
____
____
____

3. preparation of alkanes

a) Mention one common method for the preparation of alkanes

____

Figure 1: worksheet for students group work

The teacher moves round to inspect work being done by the groups for 11 minutes.

Provide feedback: The goal is to provide immediate feedback for student on their progress. The teacher selects three groups randomly to present their solutions to the questions given in 10 minutes. The teacher provides immediate feedback on the group's presentation.

Assess performance: The purpose is to determine the degree of students' conceptual understanding in order to diagnose existing issues and provide further assistance. The teacher dissolves the groups and provides questions for students to solve individually on isomerism in hydrocarbons, physical/chemical properties of alkanes, and preparation of alkanes on the provided worksheet in figure 2:

1. **Define Isomerism in hydrocarbons and give examples.**

a) How many isomeric alkanes of the molecular formula are there in C5H12 ________________________

A. Draw and name all the isomeric structures formed from C5H12

2. **Physical and chemical properties each in alkanes**

a) The reaction of propane with bromine is called? __________________________________

A. Mention the products formed when methane reacts with oxygen

____

____

Which of the following alkanes is the least soluble in water?

A. Butane
B. Ethane
C. Methane
D. Propane

Give reasons

____
____
____

3. preparation of alkanes

Mention the common method for the preparation of ethane

____

Figure 2: worksheet for students' independent work

Students respond by solving the questions given for 8 minutes. Teacher randomly calls 7 students to present their solution to each of the questions and provides immediate feedback on the students' responses in 5 minutes.

Enhance retention and transfer: The purpose of this last stage of instruction is to aid students in acquiring knowledge and internalising the isomerism in hydrocarbons, physical/chemical properties of alkanes, and preparation of alkanes concepts they had acquired in order to promote retention and transfer. The teacher asks students to review the lesson on isomerism in hydrocarbons, physical/chemical properties, and preparation of alkanes in 10 minutes. Students respond by reviewing what has been learned.

Lesson 4

Subject: Organic chemistry

Topic: Hydrocarbons

Subtopic: 1. Physical/chemical properties of alkenes and alkynes

2. Preparation of alkenes and alkynes

Duration: 120mumites

Learning resources: video simulations, electronic projector

Gain attention: In this initial stage of the lesson, the objective is to attract the students' attention. To do this, the teacher shows a short funny video. Students watch video for 3 minutes to focus their attention on upcoming lesson.

Recall of previous knowledge: At this stage of instruction, the teacher will integrate the previous knowledge of students and the incoming Physical/chemical properties of alkenes/alkynes and preparation of alkenes/alkynes concepts to enable an attentive and expectant student to obtain mastery of alkane concept. The teacher reviews students' previous knowledge on isomerism of hydrocarbons and physical and chemical properties of alkanes for 5 minutes.

Outlining learning objectives: After gaining the attention of students through showcasing a funny video, teacher will stimulate students' cognitive processes by informing them of anticipated learning outcomes. The teacher states and shares the lesson's learning objectives with students in 5 minutes. By the end of this lesson, you should be able to:

1. State at least 3 physical and chemical properties of alkenes and alkynes
2. State at least one methods of alkene and alkyne preparation

Students acknowledge the lesson objectives by writing them in their note books.

Present content: The purpose of this stage of instruction is for the teacher to present the alkane concepts to be learned through a series of activities that involve the students. The teacher divides the students into 6 groups of seven members each. Subsequently, the teacher presents videos on the Physical/chemical properties of alkenes/alkynes and preparation of alkenes/alkynes while the students watch attentively and take notes on important details for 18-minute. The teacher instructs the students to work together and share ideas in their designated groups on isomerism in hydrocarbons, physical/chemical properties of alkanes, and preparation of alkanes encouraging them to engage in critical thinking and effective communication. Students respond by working together and sharing ideas in their assigned groups on Physical/chemical properties of alkenes/alkynes and preparation of alkenes/alkynes for 5 minutes. Afterwards, the teacher selects three groups randomly to present their findings on Physical/chemical properties of alkenes/alkynes and preparation of alkenes/alkynes. Students respond by presenting their findings to the entire class in 5 minutes each.

Provide learner guidance: The purpose of this instructional stage is to lead students through a step-by-step explanation, using PowerPoint, to help them learn and retain the concept. The teacher presents a 25-minute PowerPoint on Physical/chemical properties of alkenes/alkynes and preparation of alkenes/alkynes.

Elicit performance (practice): The purpose of this stage of instruction is to activate students' thinking processes to aid in the internalization of isomerism in hydrocarbons, physical/chemical properties of alkanes, and preparation of alkanes and to verify correct comprehension of these concepts. The teacher asks the groups to provide answers to questions on Physical/chemical properties of alkenes/alkynes and preparation of alkenes/alkynes in the worksheet, as given in figure 1:

1. **physical and chemical properties of alkenes and alkynes**

a) Alkenes are generally more reactive than alkynes of the same carbon chain length.
A. False
B. True

Give reasons

____
____
____
____

b) Alkenes have a Higher boiling point than alkynes of the same carbon chain length.
A. False
B. True

Give reasons

____
____
____
____

c) Halogenation is a common reaction of alkenes and alkynes with a palladium catalyst and hydrogen gas to form an alkane?
A. False
B. True

Give reasons

____
____
____
____

d) Triple bond character properties of alkynes allow them to have a shorter carbon-carbon bond length than alkenes of similar molecular weight?
A. False
B. True

Give reasons

____
____
____

2. Alkene and Alkyne preparation

a) Dehydration of alcohols is a common method for preparing alkenes and alkynes from alcohols?
A. False
B. True

Give reasons

____
____
____
____

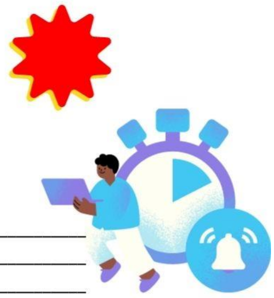
Figure 1: worksheet for students group work

The teacher moves round to inspect work being done by the groups for 11 minutes.

Provide feedback: The goal is to provide immediate feedback for student on their progress. The teacher selects three groups randomly to present their solutions to the questions given in 10 minutes. The teacher provides immediate feedback on the group's presentation.

Assess performance: The purpose is to determine the degree of students' conceptual understanding in order to diagnose existing issues and provide further assistance. The teacher dissolves the groups and provides questions for students to solve individually on Physical/chemical properties of alkenes/alkynes and preparation of alkenes/alkynes on the provided worksheet in figure 2:

1. **physical and chemical properties of alkenes and alkynes**



a) Alkenes are generally more reactive than alkynes of the same carbon chain length.
A. False
B. True

Give reasons
____
____
____
____

b) Alkenes have a Higher boiling point than alkynes of the same carbon chain length.
A. False
B. True

Give reasons
____
____
____
____

halogenation is a common reaction of alkenes and alkynes with a palladium catalyst and hydrogen gas to form an alkane?
A. False
B. True

Give reasons
____
____
____
____

Triple bond character properties of alkynes allow them to have a shorter carbon-carbon bond length than alkenes of similar molecular weight?
A. False
B. True

Give reasons
____
____
____

Alkene and Alkyne preparation

Dehydration of alcohols is a common method for preparing alkenes and alkynes from alcohols?
A. False
B. True

Give reasons
____
____
____
____

Figure 2: worksheet for students' independent work

Students respond by solving the questions given for 8 minutes. Teacher randomly calls 7 students to present their solution to each of the questions and provides immediate feedback on the students' responses in 5 minutes.

Enhance retention and transfer: The purpose of this last stage of instruction is to aid students in acquiring knowledge and internalising the Physical/chemical properties of alkenes/alkynes and preparation of alkenes/alkynes concepts they had acquired in order to promote retention and transfer. The teacher asks students to review the lesson on Physical/chemical properties of alkenes/alkynes and preparation of alkenes/alkynes in 10 minutes. Students respond by reviewing what has been learned.

Lesson 5

Subject: Organic chemistry

Topic: Hydrocarbons

Subtopic:

1. Structure of benzene
2. Reactions of benzene
3. Naming of mono-substituted benzene

Duration: 120mumites

Learning resources: videos, ChemDraw software, models, electronic projector

- ChemDraw software: used for drawing chemical structures and reactions. It is considered a valuable learning resource for students studying chemistry as it allows them to visualize chemical structures and reactions in a digital format

Gain attention: In this initial stage of the lesson, the objective is to attract the students' attention. To do this, the teacher shows a short video on uses of benzene. Students watch video for 3 minutes to focus their attention on upcoming lesson.

Recall of previous knowledge: At this stage of instruction, the teacher will integrate the previous knowledge of students and the incoming benzene concepts to enable an attentive and expectant student to achieve mastery of benzene concept. The teacher reviews students' previous knowledge on naming of alkenes and alkynes for 5 minutes.

Outlining learning objectives: After gaining the attention of students through showcasing a video on kekule structure of benzene, reactions of benzene, naming of mono-substituted benzene. Teacher will stimulate students' cognitive processes by informing them of the anticipated learning outcomes. The teacher states and shares the lesson's learning objectives with students in 5 minutes. By the end of this lesson, you should be able to:

4. Draw the kekule structure of benzene
5. Mention at least two reactions of benzene with examples
6. Draw and name at least three mono-substituted benzene compounds

Students acknowledge the lesson objectives by writing them in their note books.

Present content: The purpose of this stage of instruction is for the teacher to present the benzene concepts to be learned through a series of activities that involve the students. The teacher divides the students into 6 groups of seven members each. Subsequently, the teacher presents videos on the kekule structure of benzene, reactions of benzene, naming of mono-substitued benzene while the students watch attentively and take notes on important details for 18-minute. The teacher instructs the students to work together and share ideas in their designated groups on the kekule structure of benzene, reactions of benzene, naming of mono-substituted benzene encouraging them to engage in critical thinking and effective communication. Students respond by working together and sharing ideas in their assigned groups on the kekule structure of benzene, reactions of benzene, naming of mono-substituted benzene for 10 minutes. Afterwards, the teacher selects three groups randomly to present their findings on isomerism in hydrocarbons, physical/chemical properties of alkanes, and preparation of alkanes. Students respond by presenting their findings to the entire class in 5 minutes each.

Provide learner guidance: The purpose of this instructional stage is to lead students through a step-by-step explanation, using PowerPoint and ChemDraw software, and models, to help them learn and retain the concept. The teacher presents a 20-minute PowerPoint on the kekule structure of benzene reactions of benzene, naming of mono-substituted benzene. Then, the teacher uses ChemDraw software and models to show students the 2D and 3D structural presentation of benzene for 3 minutes.

Elicit performance (practice): The purpose of this stage of instruction is to activate students' thinking processes to aid in the internalization of the kekule structure of benzene, reactions of benzene, naming of mono-substituted benzene and to verify correct comprehension of these concepts. The teacher asks the groups to provide answers to questions on the kekule structure of benzene, reactions of benzene, naming of mono-substituted benzene in the worksheet, as given in figure 1:

benzene

1. Draw the kekule structure of benzene

2. Mention at least two reactions of benzene with examples

3. Draw the following named mono-substituted benzene compounds
   1. Nitrobenzene
   2. bromobenzene
   3. chlorobenzene

solution

Figure 1: worksheet for students group work

The teacher moves round to inspect work being done by the groups for 8 minutes.

Provide feedback: The goal is to provide immediate feedback for student on their progress. The teacher selects three groups randomly to present their solutions to the questions given in 10 minutes. The teacher provides immediate feedback on the group's presentation.

Assess performance: The purpose is to determine the degree of students' conceptual understanding in order to diagnose existing issues and provide further assistance. The teacher dissolves the groups and provides questions for students to solve individually on the kekule structure of benzene, reactions of benzene, naming of mono-substituted benzene on the provided worksheet in figure 2:

benzene

1. **Draw the kekule structure of benzene**

2. **Complete the following reactions:**

3. **Draw the following named mono-substituted benzene compounds**
   1. ethylbenzene
   2. Phenol
   3. Aniline

solution

Figure 2: worksheet for students' independent work

Students respond by solving the questions given for 8 minutes. Teacher randomly calls 7 students to present their solution to each of the questions and provides immediate feedback on the students' responses in 5 minutes.

Enhance retention and transfer: The purpose of this last stage of instruction is to aid students in acquiring knowledge and internalising the kekule structure of benzene, reactions of benzene, naming of mono-substituted benzene concepts they had acquired in order to promote retention and transfer. The teacher engages students to review the lesson on the kekule structure of benzene, reactions of benzene, naming of mono-substituted benzene in 10 minutes. Students respond by providing feedback on what has been learned.

APPENDIX J

Informed consent

Title: **Improving the teaching and learning of organic chemistry amongst senior high school students**
Principal Investigator: Nathan Ohene Gyang
Address: Department of Science Education, University of Cape Coast, Ghana.

General Information about Research

This study aims to investigate methods for enhancing the theoretical understanding of organic chemistry among SHS science students. I would want to collect data from your class through interviews (which will be recorded), instructional sessions, test responses, and surveys. The data obtained from individuals will be securely stored in an encoded format to preserve confidentiality and anonymity. Participants will not be required to provide personal identifying information such as their name or phone number, so eliminating any potential linkage between the completed form and their identity. The data has the potential to be stored indefinitely for the purpose of conducting future analyses, and there are currently no intentions to delete the dataset. Your written statements may be utilized in my thesis and other publications pertaining to my research. There will be no possibility of identifying you in these publications. The involvement of individuals in this research is completely optional, and they have the option to resign from the study at any point without facing any negative repercussions. Furthermore, it is important to note that your personal identity will remain undisclosed in search engine results, and the confidentiality of my provided information will be upheld at all times. The duration of the interview sessions is estimated to be around 15 minutes, however the instructional session will span the entirety of the class lesson duration. Participants will not receive any form of compensation for their involvement in the research. Participants have the option to voluntarily resign from the research without facing any negative repercussions. The revocation of this consent is permissible without any adverse consequences. You have the right to ask and have questions answered concerning the study and that these questions, if any, have been answered to your satisfaction. I may be reached at the following contact details: 0244871418 or by email at nathan.gyang@stu.ucc.edu.gh. In the event that you possess inquiries regarding your entitlements as a participant in this study or perceive any potential risks associated with your involvement, it is possible to seek clarification and resolution by reaching out to my supervisor, Prof. Victor Yao Atsu Barku (Phone: 0244895213), and Dr. Kenneth Adu-Gyamfi (Phone: 0555731806). They will be able to address any concerns or queries you may have regarding this research endeavour. The results will be sent to you upon your request.

Your rights as a Participant

The research in question has undergone a thorough evaluation and received approval from the Institutional Review Board (IRB) of the University of Cape Coast (UCC). If there are any inquiries regarding the rights of those participating in research, please reach out to the Administrator at the Institutional Review Board (IRB) Office during the designated hours of 8:00 am to 4:30 pm. Contact may be made via the following phone lines: 0558093143, 0508878309, or 0244207814. Alternatively, correspondence can be sent via email to irb@ucc.edu.gh.

VOLUNTEER AGREEMENT

The preceding text provides a comprehensive overview of the advantages, potential drawbacks, and methodologies associated with the study mentioned in the title improving the teaching and learning of organic chemistry amongst senior high school students has been read and explained to me. I have been given an opportunity to ask any questions about the research answered to my satisfaction. I agree/do not agree to participate as a volunteer.

_______________________ _______________________

Date Name and signature or mark of volunteer

If volunteers cannot read the form themselves, a witness must sign here:

I was in attendance for the presentation of the advantages, dangers, and procedures to the volunteer. All inquiries were addressed and the volunteer has consented to participate in the study.

_______________________ _______________________

Date Name and signature of witness

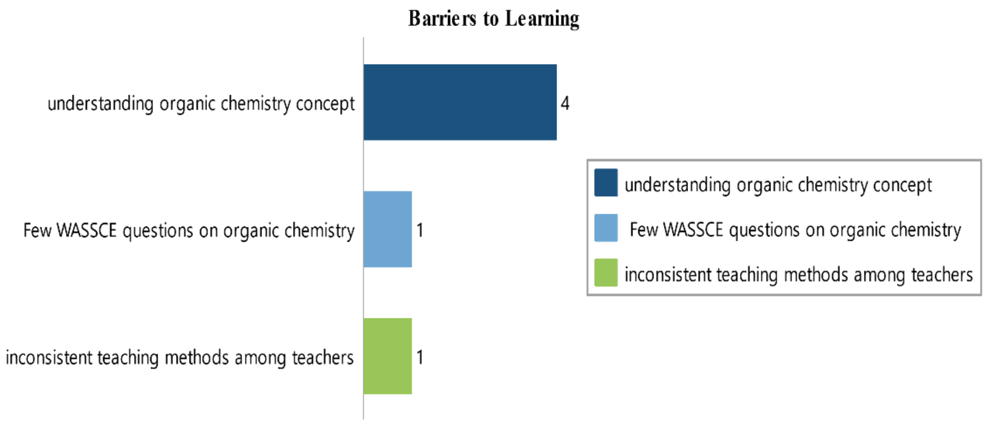
I hereby confirm that the individual in question has been provided with a comprehensive explanation about the nature and goal of this research, as well as the potential advantages and potential dangers connected with their participation.

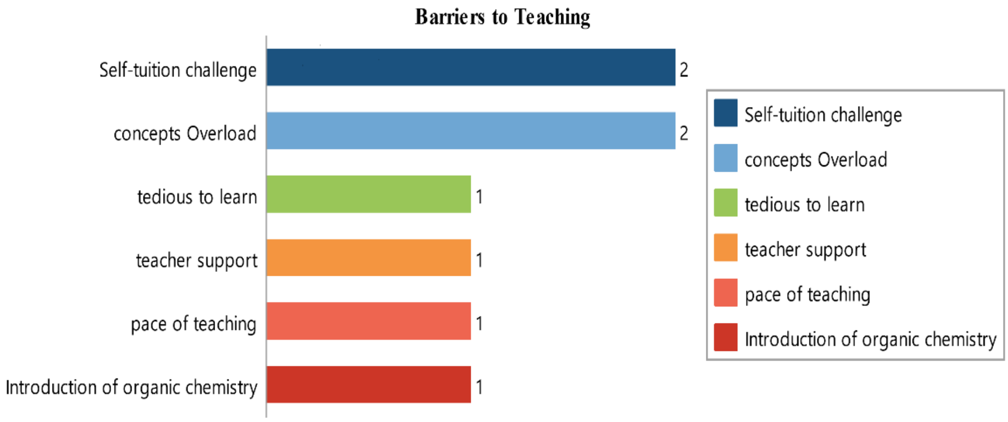
_______________________ _______________________

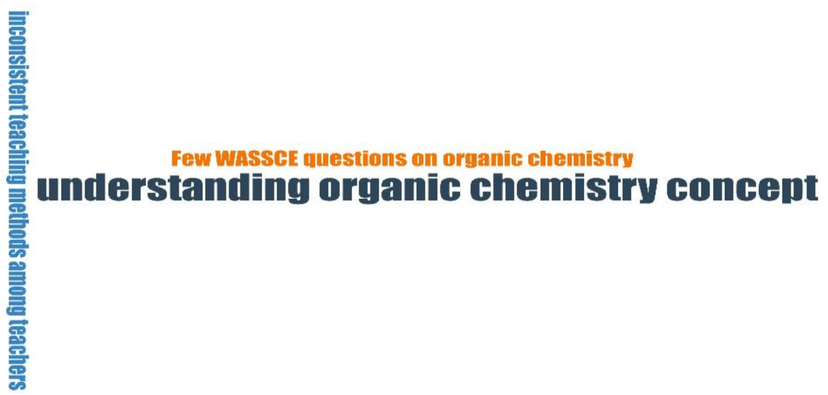
Date Name Signature of Person who Obtained Consent

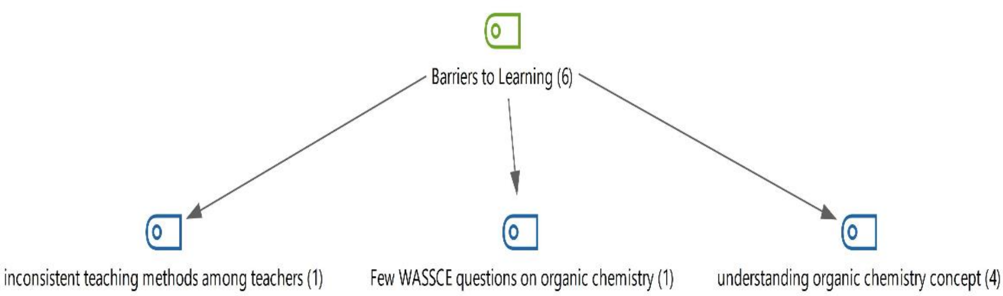
APPENDIX K

Summary of the text mapping results from students' perspective on organic chemistry teaching and learning

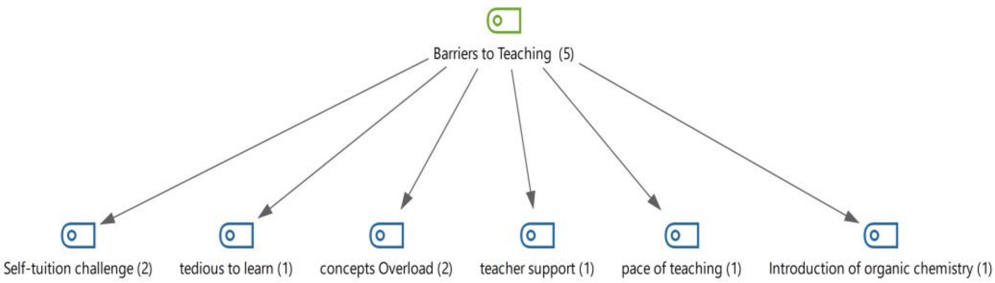


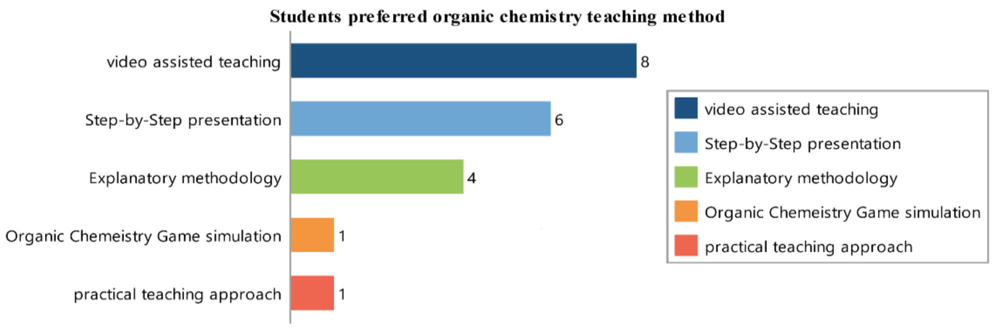




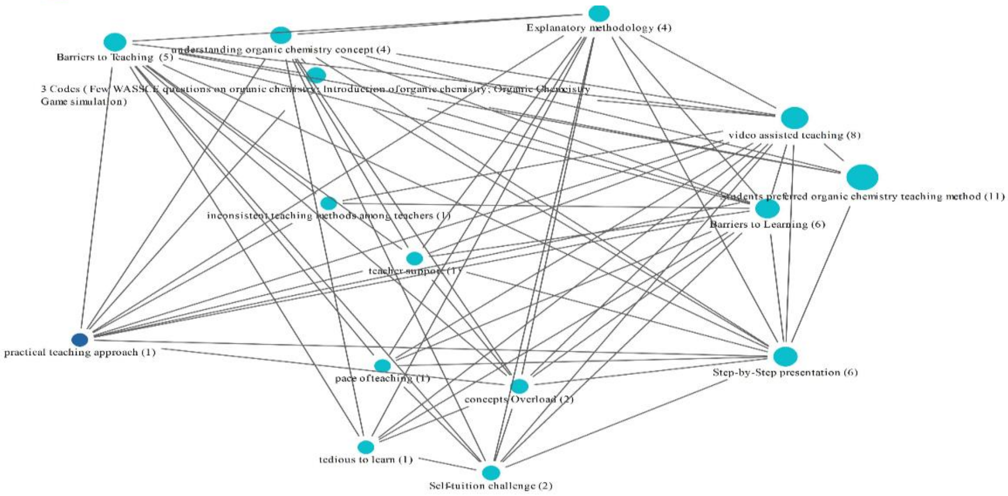



concepts Overload
pace of teaching
tedious to learn
Self-tuition challenge
Introduction of organic chemistry
teacher support


Barriers to Teaching (5)
Self-tuition challenge (2)
tedious to learn (1)
concepts Overload (2)
teacher support (1)
pace of teaching (1)
Introduction of organic chemistry (1)

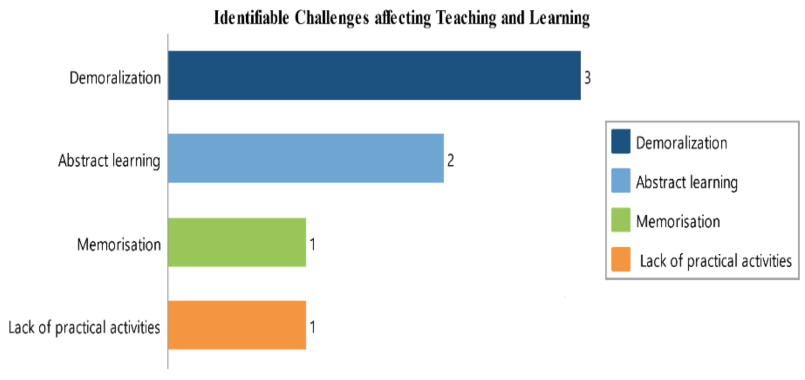

Students preferred organic chemistry teaching method
video assisted teaching
8
Step-by-Step presentation
6
Explanatory methodology
4
Organic Chemeistry Game simulation
1
practical teaching approach
1
video assisted teaching
Step-by-Step presentation
Explanatory methodology
Organic Chemeistry Game simulation
practical teaching approach

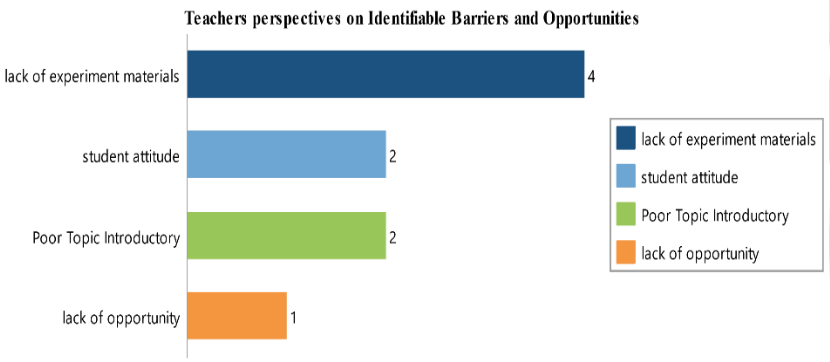

Explanatory methodology
Step-by-Step presentation
Organic Chemeistry Game simulation
practical teaching approach
video assisted teaching

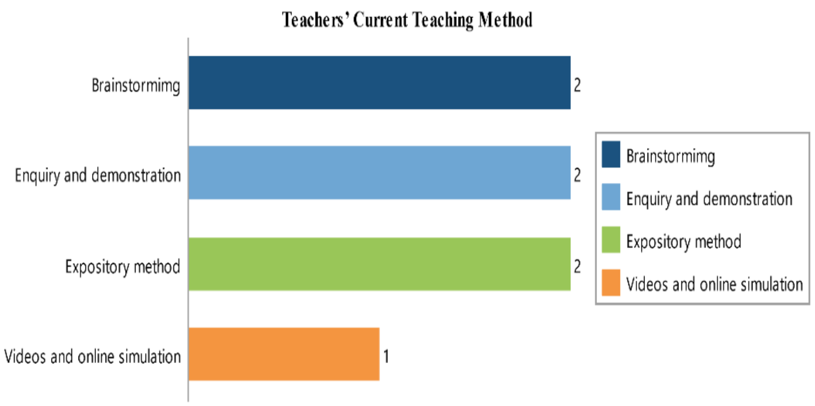

Explanatory methodology (4)
Barriers to Teaching (5)
understanding organic chemistry concept (4)
video assisted teaching (8)
Students preferred organic chemistry teaching method (11)
Barriers to Learning (6)
inconsistent teaching methods among teachers (1)
teacher support (1)
practical teaching approach (1)
pace of teaching (1)
concepts Overload (2)
Step-by-Step presentation (6)
tedious to learn (1)
Self-tuition challenge (2)

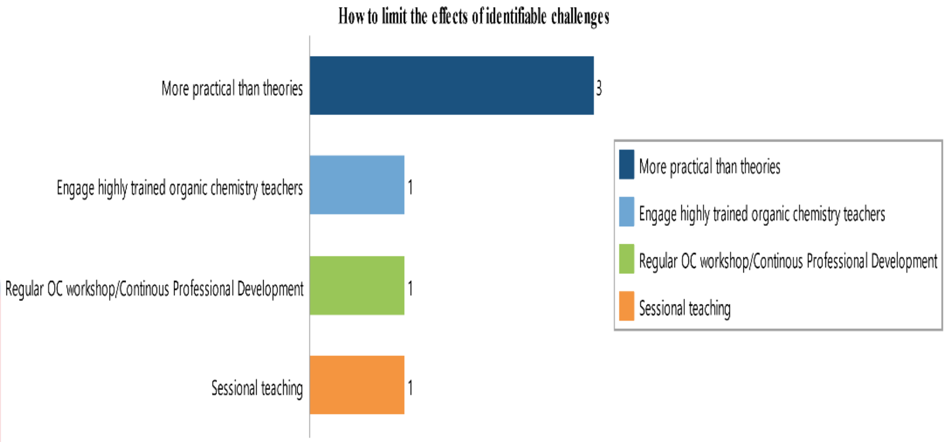
APPENDIX L

Summary of the text mapping results from teachers' perspective on organic chemistry teaching and learning



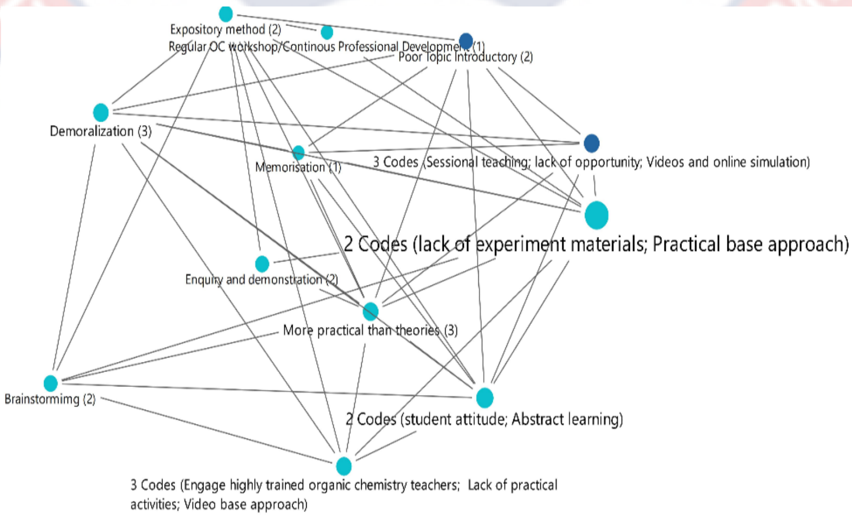





How to limit the effects of identifiable challenges
More practical than theories
3
Engage highly trained organic chemistry teachers
1
Regular OC workshop/Continous Professional Development
1
Sessional teaching
1
More practical than theories
Engage highly trained organic chemistry teachers
Regular OC workshop/Continous Professional Development
Sessional teaching


Enquiry and demonstration
Videos and online simulation
Brainstormimg
Expository method


Video base approach
Practical base approach


Expository method (2)
Regular OC workshop/Continous Professional Development (1)
Poor Topic Introductory (2)
Demoralization (3)
Memorisation (1)
3 Codes (Sessional teaching; lack of opportunity; Videos and online simulation)
2 Codes (lack of experiment materials; Practical base approach)
Enquiry and demonstration (2)
More practical than theories (3)
Brainstormimg (2)
2 Codes (student attitude; Abstract learning)
3 Codes (Engage highly trained organic chemistry teachers; Lack of practical activities; Video base approach)

APPENDIX M

STUDENTS RESPONSES SIMILARITY MATRIX

Document name	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6	Participant 7	Participant 8	Participant 9	Participant 10	Participant 11
SURVEY\Participant 1	1.00	0.56	0.50	0.67	0.56	0.56	0.56	0.50	0.67	0.56	0.61
SURVEY\Participant 2	0.56	1.00	0.61	0.67	0.67	0.78	0.56	0.61	0.67	0.67	0.61
SURVEY\Participant 3	0.50	0.61	1.00	0.61	0.72	0.61	0.50	0.67	0.50	0.61	0.56
SURVEY\Participant 4	0.67	0.67	0.61	1.00	0.67	0.67	0.67	0.72	0.78	0.67	0.72
SURVEY\Participant 5	0.56	0.67	0.72	0.67	1.00	0.78	0.67	0.72	0.67	0.78	0.72
SURVEY\Participant 6	0.56	0.78	0.61	0.67	0.78	1.00	0.78	0.83	0.78	0.89	0.83
SURVEY\Participant 7	0.56	0.56	0.50	0.67	0.67	0.78	1.00	0.83	0.89	0.89	0.94
SURVEY\Participant 8	0.50	0.61	0.67	0.72	0.72	0.83	0.83	1.00	0.83	0.94	0.89
SURVEY\Participant 9	0.67	0.67	0.50	0.78	0.67	0.78	0.89	0.83	1.00	0.89	0.94
SURVEY\Participant 10	0.56	0.67	0.61	0.67	0.78	0.89	0.89	0.94	0.89	1.00	0.94
SURVEY\Participant 11	0.61	0.61	0.56	0.72	0.72	0.83	0.94	0.89	0.94	0.94	1.00

APPENDIX N

TEACHERS RESPONSES SIMILARITY MATRIX

Document name	Participant 4	Participant 1	Participant 2	Participant 3
SURVEY\Participant 4	1.00	0.57	0.65	0.74
SURVEY\Participant 1	0.57	1.00	0.57	0.57
SURVEY\Participant 2	0.65	0.57	1.00	0.57
SURVEY\Participant 3	0.74	0.57	0.57	1.00

APPENDIX O

DESIGN GUIDELINES FOR IMPROVING STUDENT CONCEPTUAL UNDERSTANDING IN ORGANIC CHEMISTRY

The study's design-based research technique yielded the generation of a set of design guidelines that might potentially serve as a valuable resource for educators and researchers in the field of Chemistry Education. These guidelines can be utilized to construct instructional sequences for effectively teaching organic chemistry concepts at the secondary school level. The investigation has yielded the following design criteria:

a. The Gagne Nine Events of Instruction offered the teacher the opportunity to deliver the lesson sequentially. The instructional strategy takes into account external factors, such as the learning environment, resources, and management of learning activities, which interact with internal conditions, such as the learner's attitude toward the learning task, prior knowledge, and individual learning goals, to develop the anticipated learning outcomes. The outlined procedures will serve as a means for the instructor to effectively use teaching techniques and learning materials to engage the students' interest and appropriately equip them for the development of conceptual understanding.
b. Integration of video-based learning will enable the teacher to attract the attention of the students through the presentation of videos, animations, or simulations on the concepts to be taught. This will further allow the teacher to observe the class as students solves problems through sharing of ideas in groups as members help with explanations on how they arrived at solutions to the given problem. Also, this will provide the needed support to the teacher and the students to overcome the practical limitations of abstract concepts.
c. The situated learning approach will enable students to learn collaboratively in a natural environment where they are able to interact with one another through the sharing of ideas and perspectives. This will ensure that students actively participate and well-integrated into class activities. Also, this will ensure that students learn from their interactions with other group members with an opportunity to grow intellectually.
d. The integration of formative assessment technique throughout the lesson will generate student feedback to enable the teacher assess students' progress on the lesson. This will help the teacher steer learning effectively and influence students' learning processes to improve their learning outcomes through the provision of immediate feedback on students' responses.

APPENDIX P

WILCOXON SIGNED RANK TEST OUTPUT

Descriptive Statistics

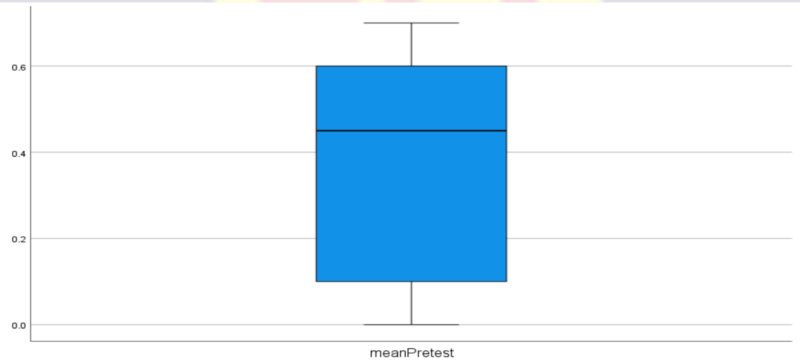
	N	Mean	Std. Deviation	Minimum	Maximum
meanPretest	22	.4045	.24972	.00	.70
meanPosttest	22	1.7409	.15632	1.40	2.00

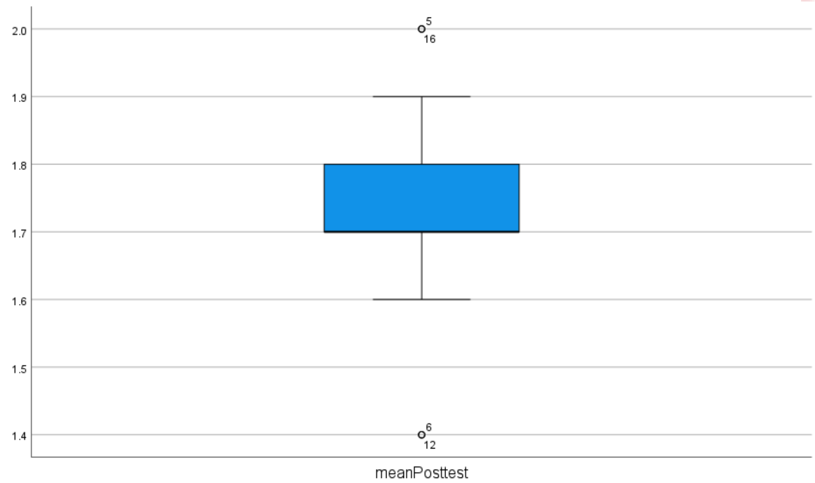
Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
meanPosttest – meanPretest	Negative Ranks	0[a]	.00	.00
	Positive Ranks	22[b]	11.50	253.00
	Ties	0[c]		
	Total	22		

	meanPosttest - meanPretest
Z	-4.112[b]
Asymp. Sig. (2-tailed)	.000





UNIVERSITY OF CAPE COAST
COLLEGE OF EDUCATION STUDIES
FACULTY OF SCIENCE AND TECHNOLOGY EDUCATION
DEPARTMENT OF SCIENCE EDUCATION

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University Post Office
Cape Coast
Ghana

Your Ref:
Our Ref: DSE/S.4/V.1/296

17th August, 2021

TO WHOM IT MAY CONCERN

Dear Sir/Madam,

LETTER OF INTRODUCTION

We write on behalf of **Nathan Ohene Gyang** a Ph.D. (Science Education) student with registration number **ED/SED/18/0004** who has been assigned to collect data at your School.

Gyang is conducting a research on the topic: **"Improving the Teaching and Learning of Organic Chemistry amongst Senior High School Students"**.

We, therefore, write to introduce and request that you grant him the needed assistance.

Counting on your usual cooperation.

Thank you.

Yours faithfully,

Dr. Kenneth Adu-Gyamfi
(Senior Lecturer)
SUPERVISOR